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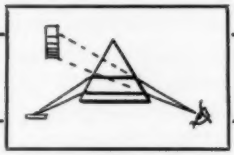

JANUARY
1931

Editorial

¶With this issue the Journal of the Optical Society begins its twenty-first volume. A new cover design and a slight change in the scheme of make-up has been adopted.

¶The table of contents for future issues will be carried on a fly leaf facing the first inside cover, and on the back of this leaf will be found information regarding the history of the Journal, a list of the board of editors, and other pertinent data.

¶The front cover page was designed by one of our distinguished artist-members, Mr. Charles Bittinger of Washington, D. C.

¶The main lettering is known as Vrana-Metria copied from the hand-drawn work of the first edition of Johann Bayer's Uranometria, 1603, with title and engravings by Alexander Mair. The slanting letters and the ornament showing the passage of light through a prism are copied from an original edition of Newton's Optics. The Frederic Ives medal, awarded by the Optical Society for distinguished work in Optics bears the same device. This device is thought to symbolize very happily geometrical, physical, physiological and psychological optics.

(THE EDITORS)

TELEVISION IN COLOR FROM MOTION PICTURE FILM

By Herbert E. Ives
[Bell Telephone Laboratories, New York, New York. Received Oct. 7, 1930]

In speculations on the possible uses for television, one project which receives considerable attention, partly because of its relative ease of accomplishment, is the transmission of images from motion picture film. It is true that the practical simultaneity of event and viewing, which is the unique offering of television, is lost when the time necessary for photographic development of the film intervenes. Nevertheless it is conceivable that if this delay is small, television from film may still possess such an advantage over the material transportation of film as to give it a real field. A further possibility, more remote, but within the range of legitimate speculation, is that television apparatus may sometime be used to receive, in the home, motion pictures of the sort now offered in the theatres or in home projection outfits. However distant these mergings of the two arts may be, the technical problems presented are pretty clearly defined, and offer interesting features for study.

Among these problems,—and perhaps the farthest cry of any—is the transmission of images in color from colored motion picture film. This paper describes a method of accomplishing this, using the receiving apparatus for television in color recently described, and special sending apparatus which utilizes the latest form of colored moving pictures—the ridged film now marketed under the name of Kodacolor.

As an introduction to the method of telecinematography in color using ridged film, it is profitable to outline how the problem could be solved with film in which the colors are incorporated by dyes (e.g. Technicolor), and the three-color transmitting and receiving system recently developed in the Bell Laboratories.[1] This may be done most easily by considering Fig. 1, where the three-color transmitting apparatus is shown in section, with the addition of film handling means. The photo-electric cell cabinet, containing three sets of color sensitive cells with appropriate filters, is indicated at C, from which three communication channels R, G and B, carry the red, green and blue signals to the receiving end. At A is the arc lamp, whose light is condensed upon the perforated disc D, which is driven by the synchronous motor M. The

[1] J. O. S. A. *20*, 11; 1930.

lens L projects an image of the disc upon the matte white screen S, from which light is reflected back into the photoelectric cells. The film F, as it unwinds from the reel R_1 onto the reel R_2, passes in front of the disc D, and as closely as is practicable to it so that the film and the disc holes are in focus together on S.

If, with the apparatus as just described, the film stands still, with a picture frame exactly filling the field aperture in front of the disc, and the disc rotates at its normal speed for television, the screen S shows a projected image of the film, colored if the film is colored, and

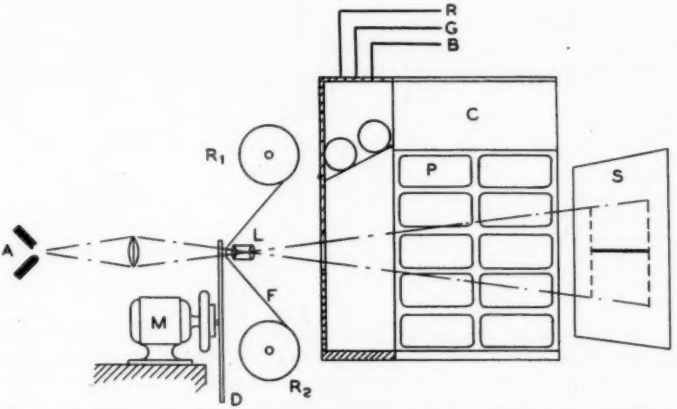

FIG. 1. *Sectional view of television sending apparatus for transmitting from colored motion picture film. A, light source; D, scanning disc; M, synchronous motor; C, photoelectric cell cabinet containing three sets of color sensitive cells with appropriate filters; F, motion picture film; L, projection lens; S, white screen.*

capable of being picked up by the photoelectric cells, and transmitted, to be received like the image of a colored object by the single disc—three lamp receiving apparatus ordinarily used for this purpose. When the film is moved in order to give a motion picture, there are two alternative forms of scanning disc available, depending on whether the motion of the film is intermittent, as in most cameras and projectors, or is continuous. In the first case a scanning disc must be used with a blank sector corresponding to the period occupied by the shift of the film between frames, as shown at D_1, Fig. 2, and a similar disc must be used at the receiving end also. The use of intermittent exposures is however not only inefficient, because of the waste of line time during the blank period, but quite unnecessary when the image is analyzed by

successive passages of a scanning aperture across the field. Instead of a disc provided with a spiral of holes it is simpler and better to use a disc with the scanning holes arranged in a circle, as shown at D_2, Fig. 2 and to give the film a uniform and continuous motion along the vertical diameter of the disc. When this is done the screen S shows merely a horizontal strip of light (indicated in the figure by the solid line) but the usual spirally perforated disc at the receiving end spreads this out into a complete picture.

This method of transmitting colored images from motion picture film, while completely practical, suffers under the disadvantage that it requires an original colored film of a sort which is both expensive and time-consuming to produce. Should television transmission from film become popular it is probable that the chief demand would be for films

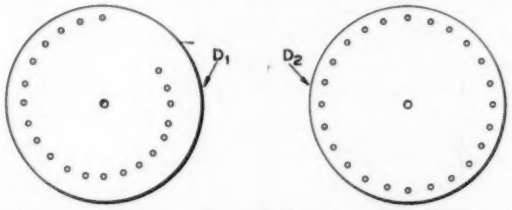

FIG. 2. *Two forms of scanning disc for use with motion picture film. D_1, disc with holes in spiral arrangement, with a blank sector corresponding to the interval between frames in intermittent projection. D_2, disc with holes in circular arrangement for use with film in continuous uniform motion.*

which would be shown but once, and for showings within a few hours at most of the event. Some form of colored film would then be called for which could be prepared quickly and cheaply, and the film process need not be one adapted for making numerous copies.

Now a form of colored motion picture which very completely meets these requirements is produced by the Kodacolor process.[2] In this the image is black and white, but is distributed into a triple linear mosaic by lenticular ridges on the film. Exposure is through a lens with three apertures, and projection is through a lens similarly equipped with three apertures, covered with red, green and blue filters. The original negative, made into a positive by a process of photographic reversal, is used for projection. There is but one film available, but this is all that is necessary for the use in television which we are considering. The film is cheap as compared to a film in which the color is added by a dying

[2] Photographic Journal, Sept. 1929, p. 402.

process, and the time required to prepare it for projection is a matter of hours instead of days. With a realization of its advantages for use in television in color from film, how can it be utilized?

The method of using Kodacolor film may be most comprehensively described by saying that the film is to be projected as though for display upon a screen, but that the three beams of light issuing from the projection lens are directed each into a separate photoelectric cell for television transmission. With the details of the apparatus shown in Fig. 1 in mind, the Kodacolor film arrangement is readily grasped from

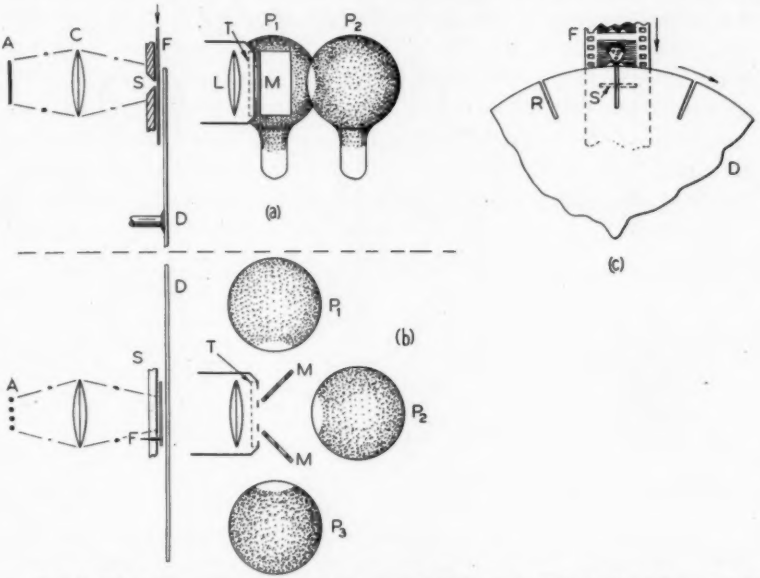

FIG. 3. *Television scanning apparatus for use with Kodacolor (colorless) ridged film. A, light source; C, condensing lens; F, film; S, slot, transverse to direction of film motion; D, scanning disc, provided with radial slots R; L, projection lens; T, position of color filters used for screen projection; P_1, P_2, P_3, three photoelectric cells; M, mirrors.*

Fig. 3. where the upper view (a) shows the elevation, the middle view (b) the plan, and (c) shows a detail of the scanning disc and film. Starting with the light source *A*, the light is condensed by the condenser system *C* on the film *F*, which moves continuously past the slot *S* and directly behind the disc *D*. The disc is shown as provided with radial slots *R*, these together with the fixed slot *S* forming the scanning holes. After passing through the film and disc the light is projected as if to

a screen by the lens L, in front of which is placed, in the regular projector, the set of red, green and blue filters T. For our purpose both the screen and the filters are dispensed with. After passing through the lens, the light is diverted into three photo-electric cells, P_1, P_2 and P_3 by the mirrors M. These cells are all similar, and need not be color sensitive. The filters are omitted as obviously unnecessary—color is not needed until the signals are received and recombined at the receiving disc where the same apparatus is used as for the reception of signals from original colored objects.

The arrangement of apparatus shown in Fig. 3 calls for the slot, film and disc being practically in contact. This condition, which must

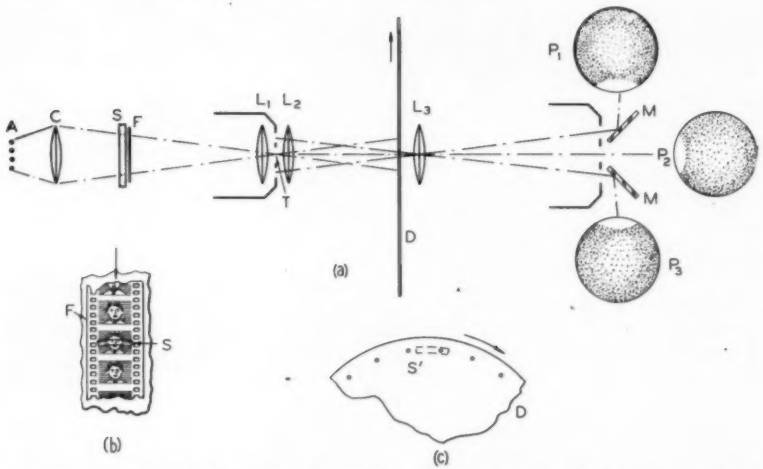

FIG. 4. *Alternative arrangement of scanning apparatus for use with Kodacolor film. The elements are the same as in Fig. 3, except that the film is imaged on the disc D by the lens system L_1, L_2, and an additional lens L_3 beyond the disc images the three apertures of the projection system onto the photoelectric cells.*

be met if color fringes are to be avoided, is likely to offer some difficulty, since both are moving at high speed. An alternative arrangement, by which the disc and film are separated, is shown in Fig. 4. Here the symbols are as in Fig. 3 and the apparatus is the same from the lamp A up to the film F. The disc is however removed to a new position beyond the projection lens L_1, which is supplemented by a short focus lens L_2 so that an image of the film F where it lies over the slot S is projected onto the disc. A third lens C_3 close to the disc images the three apertures T onto mirrors M and photoelectric cells P as before.

By this means the film image may be placed accurately in the plane of the disc and color fringes avoided.[3] Additional advantages are that the disc may be made of any convenient size, and that the radial slots to which one is practically driven by constructional difficulties in the very small disc may be replaced by holes as shown at (c).

In describing the apparatus for achieving television in colors by a beam scanning method[1] emphasis was placed on the fact that the same single scanning disc was used at each end as for monochrome work. A similar characteristic holds for the film apparatus here described. Either color or monochrome film can be used interchangeably, the latter requiring but one transmission channel. If monochrome receiving apparatus only is available when multichrome film is used it may be received as monochrome, selecting preferably the green channel as giving nearly orthochromatic effects. If three-color receiving apparatus is available of the form previously described,[1] images from monochrome film may be received on all three (red, green and blue) lamps together, adjusting their relative intensities to give white or any other desired color for the resulting monochrome image.

[3] The disc and film could be similarly separated in the form of apparatus shown in Fig. 1 although the necessity is not so apparent.

A MULTI-CHANNEL TELEVISION APPARATUS

By Herbert E. Ives

[Bell Telephone Laboratories, 463 West St., New York, N.Y. Received Oct. 24, 1930]

If, in a received television image, the individual image elements are, as they should be, of such a size as to be just indistinguishable, or unresolved, at a given observing distance, the number of image elements increases directly with the area of the image. The number of such indistinguishable elements in everyday scenes, in the news photograph, or in the frame of an ordinary motion picture is astonishingly large. An electrically transmitted photograph 5 inches by 7 inches in size, having 100 scanning strips per inch, has a field of view and a degree of definition of detail, which, experience shows, are adequate (although with little margin) for the majority of news event pictures. It is undoubtedly a picture of this sort that the television enthusiast has in the back of his mind when he predicts carrying the stage and the motion picture screen into the home over electrical communication channels. In this picture, the number of image elements is 350,000. At a repetition speed of 20 per second (24 per second has now become standard with sound films) this means the transmission of television signals at the rate of 7,000,000 per second,—a frequency band of 3-1/2 million cycles on a single sideband basis. This may be compared to the 5000 cycles in each sideband of the sound radio program, or it may be evaluated economically as the equivalent of a thousand telephone channels.

When we examine what has been achieved thus far in television, we find that the type of image successfully transmitted falls very far short of the finely detailed picture just considered. Probably the most satisfactory example of television thus far demonstrated is the 72 line picture used in the two-way television-telephone installation of the American Telephone and Telegraph Company in New York.[1] Here the object to be transmitted is definitely restricted to the human face, which fills the whole field of view, and is adequately rendered by the 4000 image elements used.

The gap between the 4000 elements of this image and the 350,000 considered above is enormous, not only in figures, but in terms of technical possibility of bridging. Even if we are forced to content ourselves with relatively simple types of scenes for television transmission,

[1] Bell System Technical Journal, July 1930, p. 448.

still the fact must be squarely faced that a very much larger number of image elements must be transmitted than has thus far been found possible; and a far wider frequency band utilized than has ever been used in any communication problem. Now the situation is, simply stated, that *all parts of the television system are already having serious difficulty in handling the 4000 element image.* Consequently, a *major problem in television progress is to develop means to extend the practical frequency range.*

It will be worth while to survey briefly the points in a television system where difficulty is now encountered when the attempt is made to increase the amount of image detail and the accompanying band of transmitted frequencies. Consider in turn the scanning discs at sending and receiving ends, the photoelectric cells, the amplifying systems, the transmission channels, the receiving lamps.

In the scanning disc at the sending end, which we shall assume arranged for direct scanning, increased detail means either loss of light or increase in the size of the disc. In either case, the factor of change involved is large. For instance, if the number of scanning holes is doubled in a disc of given size, providing four times the number of image elements, the holes must be spaced at half the angular distance apart, and twice the number of holes, imagined placed end to end, must be included in this half diameter scanning field. The holes will therefore be of one-quarter the diameter or 1/16 the area. The light falling on the photoelectric cell at any instant is the light transmitted by one hole; in this case, 1/16 the amount with the disc of half the number of holes. In general, the light transmitted by the disc to the cell decreases as the square of the number of image elements. If the disc is enlarged so as to hold the transmitted light unchanged, its diameter increases directly as the number of image elements. It is obvious that any considerable increase in the number of image elements—such as ten times—demands either enormously increased sensitiveness in our photo-responsive devices, or quite fabulous sizes of discs. Perhaps the most pertinent conclusion from this survey is that the disc, while quite the simplest means for scanning images of few elements, is entirely impractical when really large numbers of image elements are in question. As yet however no practical substitute for the disc of essentially different character has appeared.

Turning now to the photoelectric cell. The question of adequate sensitiveness to handle a large number of image elements is intimately connected with the method of scanning, as has just been brought out,

so that no simple answer is possible. It is however probable that a very considerable increase in sensitiveness over anything now available must be anticipated, whatever scanning device is adopted. In the matter of frequency range there is definite information.[2] In cells depending on gas amplification (such as argon or neon) a characteristic behavior is a falling off of output with frequency, greater the higher the voltage used, which, becoming noticeable at about 20,000 cycles, may at 100,000 cycles be so considerable as to constitute a practical block to transmission. Vacuum cells are free from this failing, but are much less sensitive. Systematic experiment and development of photoelectric cells with particular reference to extending their range of frequency response is indicated as a necessary step in the attainment of a many element image.

Taking up next the circuits associated with the photoelectric cell, we find, in general, that the higher frequencies progressively suffer from the electrical capacity of cells and associated wiring and amplifier tubes. This in turn calls for auxiliary equalizing circuits, with attendant problems of phase adjustment, and for increased amplification. Amplifiers capable of handling frequency bands extending from low frequencies up to 100,000 cycles or over offer serious problems.

Communication channels, either wire or radio, are characterized by increasing difficulty of transmission as the frequency band is widened. In radio, fading, different at different frequencies, and various forms of interference stand in the way of securing a wide frequency channel of uniform efficiency. In wire, progressive attenuation at higher frequencies, shift of phase, and cross-induction between circuits offer serious obstacles. Transformers and intermediate amplifiers or repeaters capable of handling the wide frequency bands here in question also present serious problems.

At the receiving end of the television system, conditions are similar to the sending end. The neon glow lamp, commonly used for reception, is already failing to follow the television signals well below 40,000 cycles, and, in the case of the 4000 element image above referred to, the neon must be assisted by a frequently renewed admixture of hydrogen, which again cannot be expected to increase the frequency range indefinitely. In the scanning disc, as at the sending end, increasing the number of image elements, rapidly reduces the amount of light in the image. With a plate glow lamp of given brightness, the apparent brightness of the image is inversely as the number of image elements.

[2] Loc. cit. p. 456.

From this rapid survey, it is clear that at practically every stage in the television system, we encounter serious difficulties when a large increase in image elements is contemplated. It is not claimed that these difficulties are insuperable. One of the chief uses of a tabulation of difficulties is to aid in marshalling the attack upon them. But the existing situation is that if a many element television image is called for today, it is not available, and *one of the chief obstacles is the difficulty of generating, transmitting, and recovering signals extending over wide frequency bands.*

One alternative, which prompted the experimental work to be described below, is the *use of multiple scanning, and multiple channel transmission.* The general idea, which is obvious from the name given to the method, is to divide the image into groups of elements, the various groups to be simultaneously scanned, and to transmit the signals from the several groups through separate transmission channels. In place of apparatus to generate and transmit a frequency band of n cycles, we arrange m scanning processes each to provide frequency bands of n/m cycles width; n/m being chosen as within the limits set by the available practical elements of a television system. It will appear that the method which has been developed does provide an image of many fold more image elements than heretofore, and may make easier the problem of transmission over practical transmission lines.

DESCRIPTION OF A THREE CHANNEL APPARATUS

The multi-scanning apparatus which has been constructed and given experimental test uses scanning discs over whose holes are placed prisms of several different angles. At the sending end, the beams of light from successive holes are thereby diverted to different photoelectric cells. At the receiving end, the prisms similarly take beams of light from several lamps and divert them to a common direction. The mode of action of the prisms is illustrated in Fig. 1a, where a three-channel arrangement is shown, which is that actually used in the experimental apparatus. In the figure, the disc holes are shown disposed in a spiral, at such angular distances apart that three holes are always included in the frame f. Over the first hole of a set of three is placed a prism P_1 which diverts the normally incident light upward; the second hole is left clear; the third is covered by a prism P_2 turned to divert the light downward. If we imagine the prisms removed and a single channel used instead of the three that are proposed, it is clear that the holes would have to be spaced three times as far apart so that no more

than one would be included in the frame f at one time. The diameters of the holes, and the radial separation of the first and last in the spiral would be unchanged. Quite apart therefore from the smaller frequency bands which are sufficient to carry each of the three sets of signals, which is the principal objective sought, there is realized in this arrangement a reduced size of apparatus for the same size of disc holes.

Studying more closely the division of the light into three sets of beams, it is important to note that the signals transmitted by any one of the three sets of holes are continuous—as one hole of a given prism series passes out of the frame the next of the same series comes in.

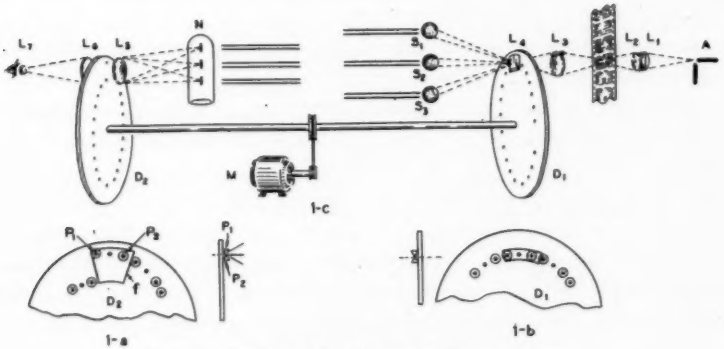

FIG. 1. *Schematic of three channel television apparatus.*

(a) *Receiving end disc with spiral of holes provided with prisms.*
(b) *Sending end disc with circle of holes provided with prisms.*
(c) *General arrangement of apparatus.*

The signals generated in each photoelectric cell are accordingly exactly like those of a single channel system.

Before describing the details of the apparatus, the general relationship between the number of image elements, band width, number of channels, and shape of picture may be developed. For this purpose, let the following symbols be used.

B = frequency band available in one channel, in cycles per second.
F = repetition frequency of images, per second.
C = number of communication channels.
n = total number of scanning holes.
a/b = ratio of tangential to radial dimensions of frame.
α = angular opening of frame.

We shall assume that the picture elements into which the frame is

imagined divided are symmetrical in shape, i.e. either circles or squares. We then have that

the number of picture elements in the radial direction = number of holes = n.

the number of picture elements in the tangential direction = $a/b \cdot n$.

Now the number of signal cycles corresponding to this number of elements is $1/2 \cdot a/b \cdot n$.

The number of cycles per second in one transit along the frame = $1/2 \cdot a/b \cdot n \cdot F$;

over the whole picture it is $1/2 \cdot a/b \cdot n \cdot F \cdot n = 1/2\ a/b \cdot F \cdot n^2$ and the number of cycles per second for each channel = $1/c \cdot 1/2\ a/b \cdot F \cdot n^2 = B$

The angular opening of the frame $\alpha = 360/n \cdot C$.

The number of picture elements $= n^2 \cdot a/b$.

These formulae may be utilized upon assuming values for any of the variables, to fix the values of the other. In the present case, it was decided for reasons of simplicity to restrict the number of channels to 3. The band width was chosen as that found feasible in the two-way television system, namely 40,000 cycles. The picture shape chosen was that of the sound motion picture, for which $a/b = 7/6$. The repetition frequency assumed was 18 per second, again following closely that of existing experimental synchronizing apparatus. Substituting these values in the formula rearranged to give n, we get for the number of holes, $n = \sqrt{2Bbc/aF} = 108$ and for α, $360/108 \times 3 = 10°$, for the number of picture elements, $n = (108)^2 \times 7/6 = 13{,}608$.

In utilizing the prism disc principle at the sending end, direct scanning, in which the object is imaged on the disc, was chosen, since beam scanning would introduce the problem of separating the light reflected from the object from the several spots simultaneously projected from the disc. Since the light going through the disc must be separated into several beams to be directed into separate photoelectric cells, the full aperture of the image forming lens must be divided by C, the number of channels, with a consequent proportional loss of light to each cell. (This loss counterbalances the decreased size of disc above noted.) It therefore becomes necessary to insure a very high illumination of the object. In the present case, it was decided to use motion picture film to provide the sending end image, since this can have a large amount of light concentrated through it by an appropriate lens system.

The use of motion picture film permitted a simplification of the transmitting disc, which is illustrated in Fig. 1b. This consists in arranging

the scanning holes in a circle instead of a spiral, and producing the longitudinal scanning of the film by giving it a continuous uniform motion at right angles to the motion of the scanning holes. The continuous motion of the film also avoids the loss of transmission time that an intermittent motion demands for the shutter interval.

At the receiving end, a spiral of holes is used as shown in Fig. 1a. there again, because of the division of the light into three beams, the angle which can be subtended by the light source (neon lamp) is much restricted. In consequence, the neon lamp cathodes are of small area, and a lens system has been used to focus their images on the pupil of

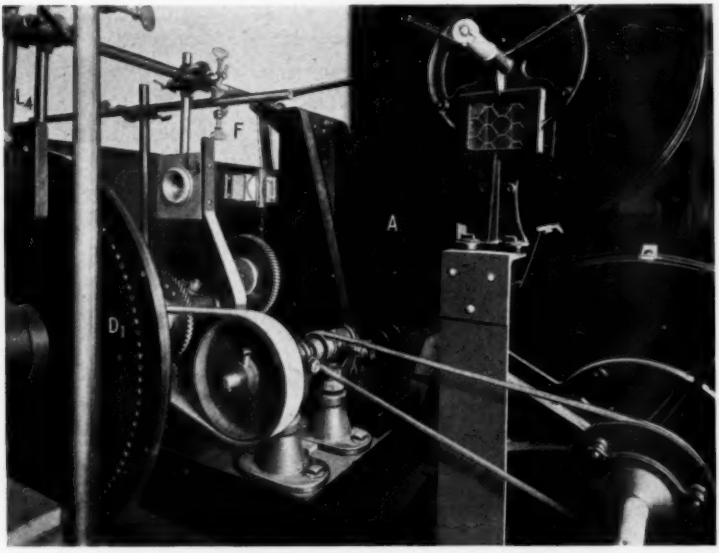

FIG. 2. *Sending end of three channel television apparatus, showing film driving arrangements.*

the observer's eye. Other methods of receiving, which promise to be less restricted as to position of observation, are possible, however, as discussed below.

With this survey of certain of the more important features of the system, we may proceed to a more detailed account of the apparatus as constructed. The general arrangement of parts is shown in Fig. 1c and in the photographs, Figs. 2, 3, 4 and 5 in all of which the symbols are uniform. Both sending and receiving discs were, for simplicity of

operation, mounted on the same axis, driven by the motor M. This means that no question of synchronization entered. Synchronization is in fact a separate problem, having nothing to do with multi-channel operation and has been very completely solved in connection with other television projects.[1] If it should be decided to transmit the multi-channel image to a distant point, the apparatus could be cut in two and each end, after separation to the desired distance, operated by synchro-

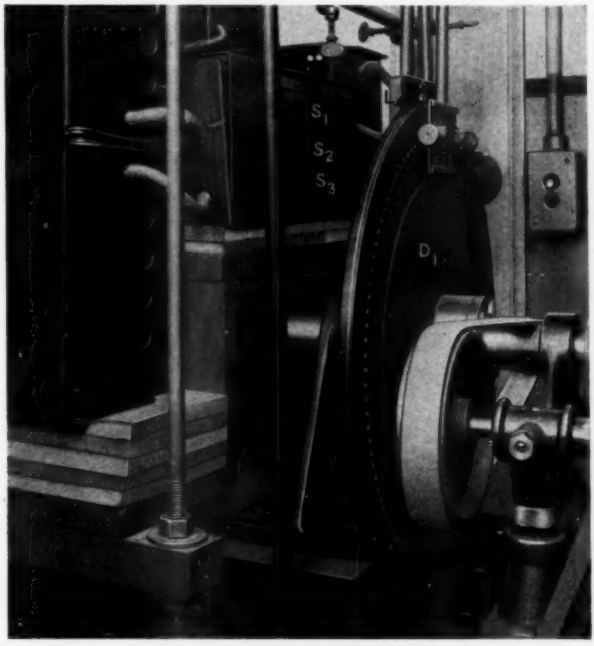

FIG. 3. *Sending end of three channel television apparatus, showing sending prism disc and photoelectric cells.*

nous motors controlled in approved fashion. Similarly, no long transmission lines were included.

Starting at the extreme right end of the schematic drawing Fig. 1c, we have an arc lamp A, a cylindrical lens L_1, a condensing lens L_2, the two lenses together concentrating a line of light on the film F. Between the film and the disc is a lens L_3 which images the film on the disc. Directly behind the disc D_1, with its circle of prism covered holes, is a second cylindrical lens L_4 which concentrates the transmitted light

laterally, upon the three photoelectric cells S_1, S_2, S_3. By virtue of this lens arrangement, the light falls upon the cells in three small practically stationary spots. Additional apparatus not shown in the diagram but visible in the photographs are gears by means of which the film is driven from the disc axle through a differential, which permits the film to be framed up and down. The light beam is directed through the film at right angles to the axis of the discs by means of two prisms, whereby certain conveniences in driving and handling the film are attained.

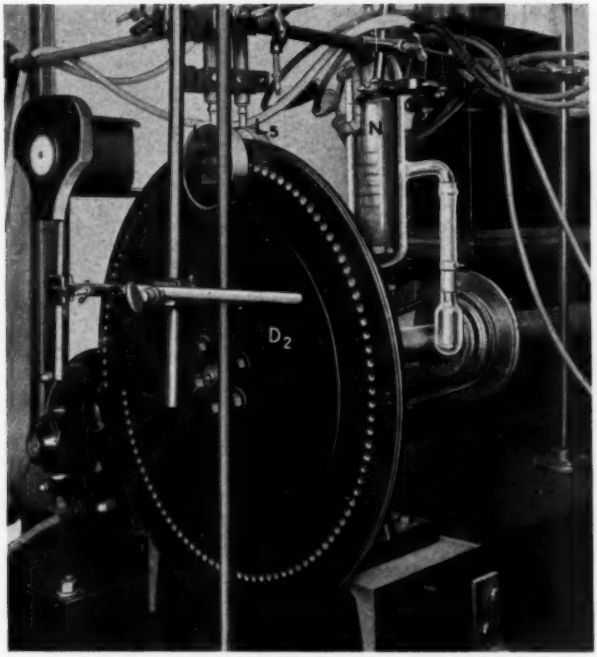

FIG. 4. *Receiving end of three channel television apparatus.*

The photoelectric cells are similar to ones previously described. The amplifier system was substantially identical with that used in the two-way television system, and need not be described again. Similarly, the amplifiers at the receiving end were the actual set used in the three-color television apparatus previously described.[2]

[2] J. O. S. A., *20*, 11; 1930.

At the receiving end, the three sets of signals were supplied to the three electrodes of a special neon lamp N, shown in Fig. 5, which is provided with a hydrogen valve to enable it to respond to the higher frequencies. Condensing lenses L_5 and L_6 image the three electrodes

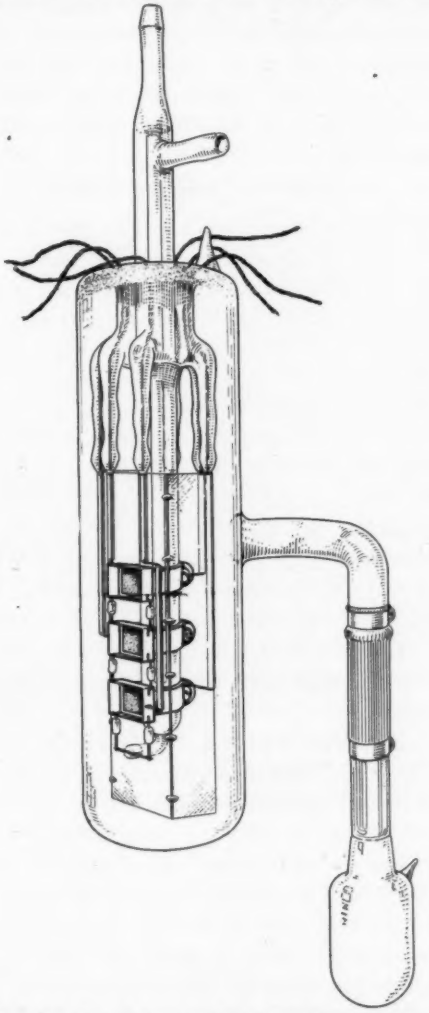

FIG. 5. *Three electrode neon lamp used for three channel television reception.*

at the eye, where another lens L_7 is placed at the eye to focus the face

of the disc D_2. By this system, nine electrode images are formed, of which three are superposed at the eye, and successive scanning holes are seen illuminated by each electrode in turn. This viewing arrangement, by which the image is visible to only a single eye, is adequate for an experimental investigation of the multi-channel method, but some other scheme would of course be needed if the method were developed into a practical form. Of several schemes, mention will be made here only of the possible use of a triple grid of neon tubes, using a triple distributor of the type used in displaying images to a large audience in our initial work in 1927.[3]

DISCUSSION OF RESULTS

The three-channel apparatus, when all parts are properly functioning, yields results strictly in agreement with the theory underlying its construction. The 13,000 element image, in resolving power and amount of detail handled, is a marked advance over the single channel 4000 element image. Even so, the experience of running through a collection of motion picture films of all types is disappointing, in that the number of subjects rendered adequately by even this number of image elements is small. "Close-ups" and scenes showing a great deal of action, are reproduced with considerable satisfaction, but scenes containing a number of full length figures, where the nature of the story is such that facial expressions should be watched, are very far from satisfactory. On the whole, the general opinion expressed in an earlier paragraph is borne out, that an enormously greater number of elements is required for a television image for general news or entertainment purposes. This however was anticipated, and the real question is whether the results of this experiment indicate that the finer grain image is best attained by resort to multi-channel means.

This leads to a discussion of what has proved to be a serious practical difficulty with the multi-channel apparatus. This is *the problem of keeping the several channels properly related to each other in signal strength.* In the experimental apparatus, the direct current components (introduced at the receiving end) and the alternating current signals, are separately controlled, manually, by potentiometers. These have fine enough steps so that with care, with a non-changing image, a uniform picture may be obtained. If however for any reason the signals on one of the channels becomes too strong or too weak, the picture exhibits at once a strongly lined appearance. The eye is quite sensitive to irregularity of this sort, and the transition from a smooth grainless

[3] Bell System Technical Journal, October 1927, pp. 551–652.

image to one showing a periodicity of 1/3 the number of constituent lines largely offsets the higher resolving power afforded by the actual number of scanning lines used. A characteristic practical defect of the system as set up is that any marked change in the general character of the signal, such as is produced by a shift from close-up to a wide angle view may throw out the existing signal balance sufficiently to show objectionable grain in the picture.

Differences of this sort in the three signals are of course caused in general by differences in the characteristics of the three circuits. Such differences can arise from overloading of amplifier tubes, whereby one or more may be working on a non-linear portion; by rectifying action of different amounts in the tubes immediately associated with the neon lamps, or in the neon lamp electrodes themselves. A remedy is the careful design and test of all parts of the system to insure the greatest possible uniformity of performance. When this is carefully done, the behavior of the three signals is reasonably satisfactory.

CONCLUSION

We are, as a consequence of this work, in a position to make a general comparison of the two chief theoretical means for achieving a television image of extreme fineness of grain, which are (1) extension of the frequency band, and (2) the use of several relatively narrow frequency bands. Both, because of the diminished amount of light which finer image structure entails, demand enhanced sensitiveness of the photosensitive elements at the sending end, and increased efficiency of the light sources at the receiving end. The multi-channel scheme described has some advantage in compactness over the equivalent single channel apparatus, but since it is restricted to narrow angles of illumination of the discs the overall efficiency of light utilization is not essentially different. Comparing now the demands made upon the the electrical systems the differences between the two methods are clear cut. Method (1) demands an extension of the frequency range of all parts of the apparatus, the attainment of which depends upon physical properties and technical devices whose mastery lies in the indefinite future. Method (2) demands a multiplication of apparatus parts, and careful design and construction of these parts so as to insure accurately similar operation of a considerable number of electrical circuits and terminal elements. The attainment of the necessary uniformity of performance of the several electrical circuits and terminal elements, while involving no fundamental problems, must present increasing difficulty with the number of channels used.

ULTRAVIOLET RADIATION FROM THE SUNLIGHT (TYPE S-1) LAMP

By A. H. Taylor
[Lighting Research Laboratory, Nela Park, Cleveland, Ohio.
Received September 27, 1930]

In the fall of 1929 a new light-source, new in principle of operation as well as in energy distribution, became commercially available.[1] It was introduced as affording a means of dual-purpose lighting, combining light for vision and radiation for health maintenance.[2] Its use will not be confined to these fields, however, for many other uses are being found.

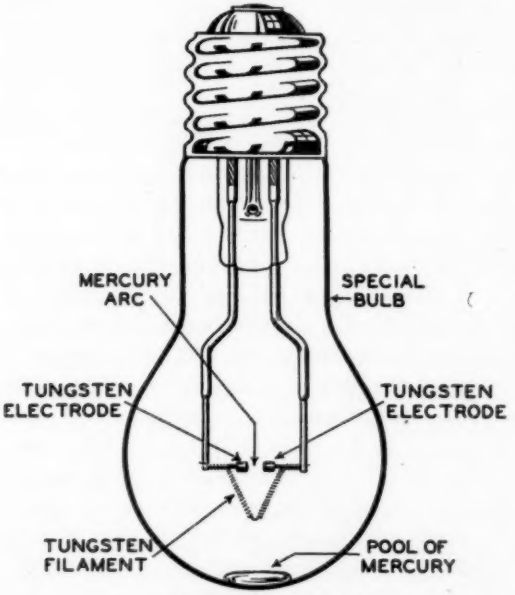

Fig. 1. *Sunlight (Type S—1) lamp.*

Description of Lamp

The new lamp (Fig. 1) is a combination of incandescent tungsten and a mercury arc, enclosed in a special bulb which has a high trans-

[1] *An Epochal Light Source*, M. Luckiesh, Electrical World, *94*, 835; 1929. Since the present manuscript was submitted the designation of this lamp has been changed to "Sunlight MAZDA Lamp (S-1)".

[2] *Artificial Sunlight*, M. Luckiesh, D. Van Nostrand Company, 1930.

mission for visible radiation and ultraviolet radiation in the region of 3000 Angstroms (for brevity referred to hereafter as λ3000), and low transmission for wave lengths shorter than λ2800 (Fig. 3). Inas-

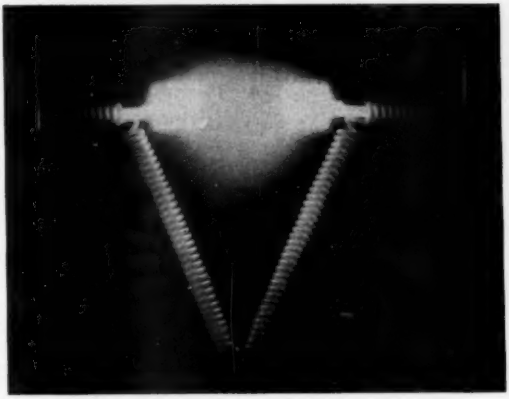

FIG. 2. *Arc, electrodes and filament of Sunlight (Type S−1) lamp, lighted.*

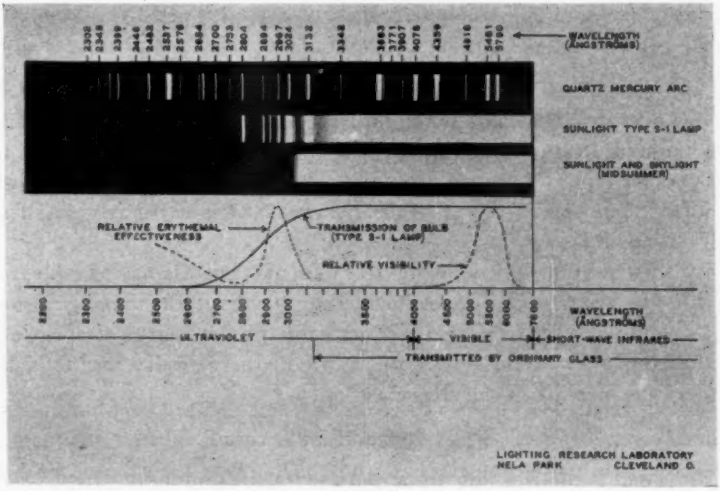

FIG. 3.

much as the spectral transmission of a filter of special glass does not end abruptly, λ2800 was adopted as the practicable short-wave cut-off

in order to conserve the radiant energy between λ2900 and λ3100 which is known to be desirable. Owing to this lack of abruptness of the short-wave cut-off of the glass, a slight amount of radiation of somewhat shorter wave lengths is also transmitted. However, the radiation from Sunlight (Type S-1) lamps has been proved by adequate tests to be so limited in quantity and quality of ultraviolet energy that the eyes are safe without goggles under reasonable usage.

ELECTRICAL CHARACTERISTICS

The lamp is operated on alternating current, with a specially designed transformer. When the current is first turned on the filament lights up, the current being approximately 9 amperes at 33 volts. Almost instantly an arc is established between the ends of the filaments where they are attached to the electrodes, and when the electrodes are heated to incandescence the arc is principally between them. When this condition exists the lamp is taking approximately 30 amperes at 11 volts. This is accomplished by using a transformer with high magnetic leakage. This results in a low power factor, less than 50%, but this characteristic is unavoidable in achieving proper operation of the lamp.

SPECTRAL ENERGY CHARACTERISTICS

The spectrum consists of the usual mercury arc lines superimposed on the continuous spectrum from incandescent tungsten. The electrodes operate at a color temperature of approximately 3200°K, and the filament at approximately 2300°K. Fig. 3 shows a spectrogram of a Type S-1 lamp. Some spectrograms show spectral lines as far down as λ2482, but the energy in those below λ2804 is extremely small as will be shown later.

The distribution of energy in the mercury lines is appreciably influenced by the temperature of the mercury pool and the vapor pressure in the lamp and these in turn are sensitive to the degree of enclosure of the lamp. An increase in temperature of the mercury results in an appreciable increase in the ultraviolet output.

ENERGY DISTRIBUTION

The energy distribution of a representative Sunlight (Type S-1) lamp has recently been measured by the author and his assistants. In selecting a lamp for the measurements fifteen lamps just received from the warehouse were compared by use of a fluorescent photometer. The maximum sensitivity of this photometer is at λ2967, which is in

the region of greatest erythemal (production of "sunburn") effectiveness[3] and antirachitic value. According to Maughan and Dye[4] "It seemed that this line in the mercury vapor spectrum was more potent (in the cure or prevention of rickets) than all the others put together; and that the antirachitic power of other radiations was about equally divided between those just longer and those just shorter than line 2968A." Four of the fifteen lamps were found to give ultraviolet values equal to the average of the group, and one of these was chosen for the tests.

OPERATING CONDITIONS

Some preliminary measurements were made with the lamp operating in the open air, but since the temperature of the mercury pool and the vapor pressure are different when operated in the open air and in an enclosure such as the Sunlamp, it appeared desirable to reproduce the latter operating condition as nearly as possible. The lamp tested was placed in a Sunlamp, with lamp axis approximately 45° from the vertical, and the lamp volts and watts determined after the lamp had become stable in temperature. In order to approximately reproduce these electrical conditions during the energy measurements the lamp was burned without reflector, axis vertical, with a 3 1/2-inch blackened copper hemisphere below. The distance of the hemisphere from the lamp was varied until a position was found where the lamp volts and watts were the same as when the lamp was operating in the Sunlamp.

INSTRUMENTS AND METHODS OF MEASUREMENT

Since the methods of measurement of energy distribution are probably of interest to workers in optics, they will be described in some detail.

Measurements in the ultraviolet, from the shortest wave length measurable to λ4359A°, were made with a Bausch and Lomb quartz monochromator equipped with a sodium photoelectric cell in quartz and used with a direct-current amplifier. The spectral sensitivity of the photoelectric cell was redetermined during the measurements by comparison with a thermopile. The collimator slit-width was 0.1 mm and the ocular slit-width 0.28 mm. Under these conditions all the principal spectral lines could be resolved and isolated. The relative

[3] *Reaction of Untanned Human Skin to Ultraviolet Radiation*, M. Luckiesh, L. L. Holladay and A. H. Taylor, J.O.S.A., *20*, 423; 1930.

[4] *The Amount of Ultraviolet Radiation Necessary to Cure Rickets*, Geo. H. Maughan and J. A. Dye, J.O.S.A., *20*, 279; 1930.

transmission of the monochromator for various wave lengths throughout the ultraviolet had previously been determined.

In the spectral region from λ4000 to λ7400 a Hilger constant-deviation spectroscope, rebuilt into a photoelectric spectrophotometer, was used with a gas-filled caesium photoelectric cell. The collimator and ocular slit-widths were, respectively, 0.1 and 0.68 mm. Under these conditions the ocular slit was always wider than the mercury lines. The width of the spectral band measured varied from 25A at λ4000 to 190A at λ7400.

In all measurements a piece of clear fused quartz, rough ground on both surfaces, was used as the secondary source of energy. It was placed near the lamp, parallel to the plane of the filament and electrodes, and received energy from arc, electrodes and filament.

In the region from λ4000 to λ7400 a "substitution" method was used. A 500-watt T-20 projection lamp with monoplane filament, operated at a color-temperature of 3125°K, was used as the standard. This made unnecessary any corrections for selective transmission by the optical system or selective response of the photoelectric cell. The spectral energy of the Type S-1 lamp was first evaluated in terms of the energy distribution of a theoretical black-body at temperature 3125°K. The continuous-spectrum portion of the energy from the test lamp was determined by measurements at wave lengths unaffected by mercury arc lines. Measurements were also made at wave lengths where mercury lines occur, and the contribution of the mercury line determined by subtracting the continuous-spectrum energy at that wave length, as determined from a smooth curve through the observations of the latter, from the total observed energy at these spectral lines. In evaluating the energy of the spectral line as distinct from the continuous spectrum due allowance was made for the dispersion of the instrument at that wave length. An example will better illustrate the application of this method.

The relative energy of the continuous spectrum portion for the spectral band λ5550 to λ5650 was arbitrarily assigned a value of 100 (the basis of black-body energy curves published by the Bureau of Standards). On this basis the energy in the continuous spectrum band 100A wide centering at λ5461 was found to be 94. Since the value for continuous and line spectra at this wave length was 250, the component due to the spectral line from the arc was the difference between these, or 156. The slit-width at this wave length was 89A, hence the *corrected* relative value of the spectral line was $89/100 \times 156$, or 139.

In order to convert *relative* energy values into percentages of the total energy radiated, the following method was used: The footcandles at a distance of approximately 3 meters from the lamp, in the direction used in the previous measurements, was determined. At the same position the watts per sq. ft. were determined by use of the thermopile and a radiation standard. From these measurements the lumens per watt radiated in this direction were determined. These data, when compared with computations of luminous efficiency using the relative energy data on the basis described above, gave a conversion factor to be applied to the latter values in order to convert them to percentages of the *total* energy radiated in this direction.

No "substitution" method was available for evaluating observations in the ultraviolet region. Hence it was necessary to determine relative energy values in this spectral range with the photoelectric cell, taking into account its spectral sensitivity as determined by comparison with

TABLE 1. *Distribution of energy in continuous and line spectra of a sunlight (Type S−1) lamp in direction normal to plane of electrodes and filament.*

Continuous spectrum				Line spectrum	
Center of 100A band	Energy in per cent of total radiated	Center of 100A band	Energy in per cent of total radiated	Wave length	Energy in per cent of total radiated
4000A°	0.019	5700A°	0.165	2537A°	0.001
4100	.026	5800	.175	2576	.002
4200	.032	5900	.186	2654	.029
4300	.040	6000	.197	2700	.007
4400	.048	6100	.205	2760	.009
4500	.055	6200	.217	2804	.039
4600	.065	6300	.226	2894	.024
4700	.076	6400	.235	2925	.018
4800	.084	6500	.246	2967	.145
4900	.093	6600	.258	3024	.553
5000	.102	6700	.267	3132	1.667
5100	.109	6800	.275	3342	0.062
5200	.118	6900	.288	3663	2.480
5300	.127	7000	.298	4047	0.253
5400	.137	7100	.308	4078	.039
5500	.146	7200	.319	4359	.386
5600	.155	7300	.326	4916	.017
		7400	.335	4960	.006
				5461	.392
				5780	.798
				6907	.009
				7082	.003

a thermopile, and to combine these data with those in the visible region by equating measurements of energy in the overlapping range, λ4000 to λ4400.

No measurements of the continuous-spectrum component below λ4000 were made, but an inspection of the data in Table 1 shows that it is small in comparison with the line component.

Throughout the spectral range of these measurements the sensitivity of the apparatus was ample for good measurements to be obtained.

GRAPHICAL REPRESENTATION OF DATA

The graphical representation of the energy data presents certain difficulties not encountered with sources which do not combine line

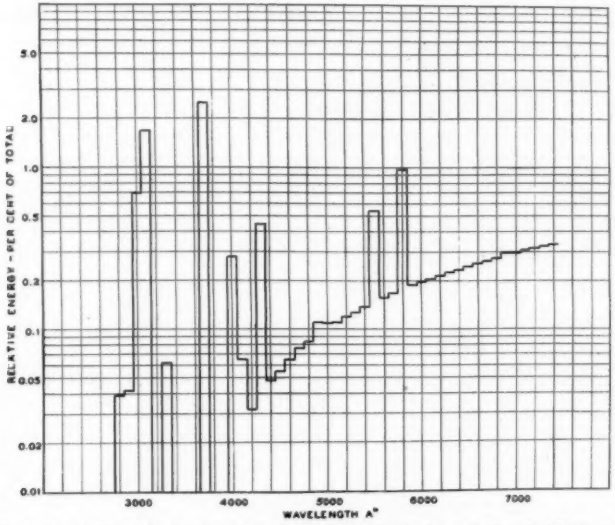

FIG. 4. *Energy distribution of sunlight (Type S−1) lamp in bands 100A wide.*

and continuous spectra. The simplest solution appears to be to divide the spectrum into blocks of definite width in angstroms and show the amount of energy in each block. In Table 1 are presented the energy distribution data for the continuous and line spectra separately, and Fig. 4 shows them combined into bands 100A wide, energy values being expressed in percentages of the total energy radiated in the specified direction. Fig. 5 shows the energy data cumulatively, i.e., from the shortest wave length to the designated wave length.

Table 2 shows the combined energy (line and continuous spectrum) in certain definite regions. The data given are for two conditions: (A) the lamp operated in open air, axis vertical, with 115 volts on the primary of the transformer; (B) with the temperature artificially altered

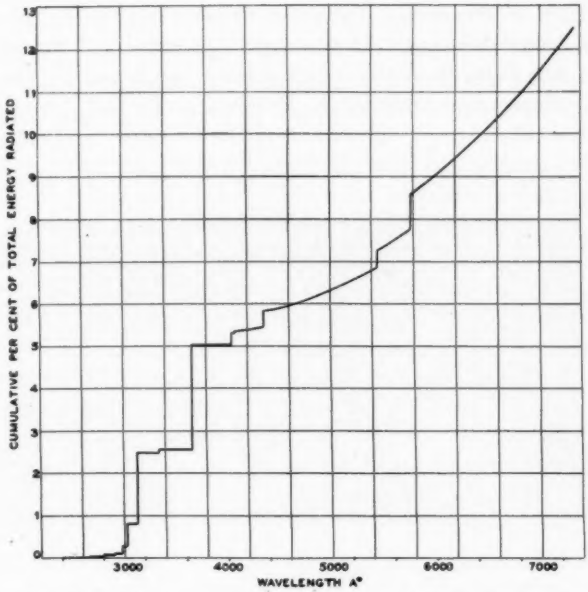

FIG. 5. *Cumulative energy distribution of sunlight (Type S—1) lamp.*

TABLE 2. *Energy of sunlight (Type S—1) lamp radiated in various spectral regions, in a direction normal to the plane of filament and electrodes, expressed in percent of the total energy radiated in this direction.*

Wave length region	Percent of total energy	
	Operated in open air	At temperature of operation in sunlamp
Shortest to λ2800	0.03	0.05
λ2800 to λ3200*	1.65	2.45
λ3200 to λ4000	1.56	2.55
λ4000 to λ7400**	9.50	7.8
Total, shortest λ to λ7400	12.74	12.85

* Biologically-important ultraviolet region.

** Visible spectrum.

to reproduce the electrical conditions obtaining in the lamp when operated in a Sunlamp reflector.

The data given here represent the energy distribution of a single lamp chosen to be as nearly representative as possible. While they probably represent the results for an average lamp reasonably well, the average of the energy given out in *all* directions might possibly be appreciably different. This is especially true with regard to the Sunlamp where much of the energy initially given out by the lamp is reflected one or more times by the aluminum reflector. Unfortunately, the analysis of the energy given out by the complete Sunlamp presents so many experimental difficulties that it does not appear justifiable to undertake it at present.

Effect of Blackening of Bulb

Because of the high temperature at which the electrodes operate the rate of blackening of these lamps is at present greater than for the ordinary gas-filled tungsten lamps. This at first raised the question whether the blackening reduced the ultraviolet output sufficiently to greatly impair the value of the lamps. Contrary to expectation, it was found that the ultraviolet output in the important biological region (λ2800 to λ3200) usually increased with the age of the lamp up to 200 hours or more. Many lamps have been tested by exposure of untanned skin at various times during their life, and with few exceptions the exposure-time required for the production of a minimum perceptible erythema (reddening of the skin) decreased as the lamps aged, up to an age of several hundred hours. One lamp after burning continuously for 400 hours produced a minimum perceptible erythema in the same exposure time as when new, although the illumination at a fixed distance had decreased to 50 percent of its initial value.

General Discussion

As a source of ultraviolet radiation, whether for health maintenance, therapeutic treatment by physicians, or for experimental work in the laboratory, this lamp is of great value. For ultraviolet radiation of wave lengths longer than λ2800 it is very valuable in the laboratory. Since the arc length between electrodes is only about 5 mm, it is possible to obtain a much greater concentration of ultraviolet with quartz lenses than is possible with the more common quartz mercury arcs. This in some measure reduces the need for high light-gathering power in quartz monochromators. The electrodes operate at a high tempera-

ture and have been successfully used as sources of continuous ultraviolet radiation. In general laboratory work these lamps have been found to be much less subject to momentary fluctuations of intensity than the quartz mercury arc. If they are ever available in quartz bulbs their usefulness as sources of the shorter ultraviolet will be greatly extended.

One peculiarity of this lamp is the almost complete absence of the line λ2537, which is usually very strong in quartz mercury arcs. Some experimental lamps were made up in quartz bulbs, and inspection of

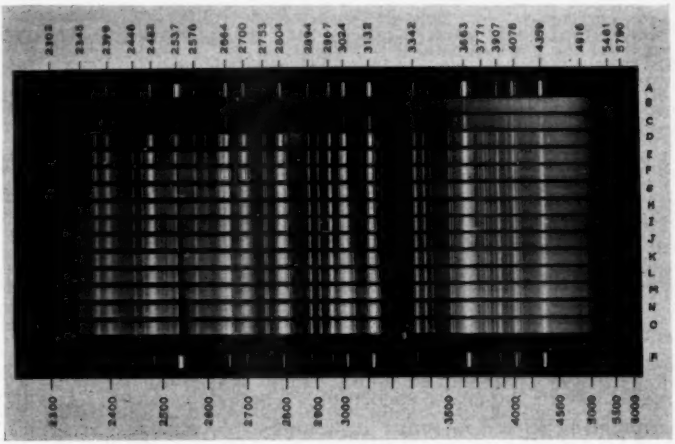

FIG. 6. *Spectrograms of radiation from a quartz mercury; arc (A and P) and from a Sunlight (Type S—1) lamp in quartz bulb at various intervals after starting, as follows: (B) 10 sec.; (C) 30 sec.; (D) 1 min.; (E) 1½ min.; (F) 2 min.; (G) 3 min.; (H) 4 min.; (I) 6 min.; (J) 8 min.; (K) 10 min.; (L) 12 min.; (M) 15 min.; (N) 20 min.; (O) 30 min.*

spectrograms showed a gap in the spectrum at this point. Acting on the assumption that this was due to absorption of the line by the mercury vapor, brought about by the vapor pressure in the lamp, Dr. M. Luckiesh had the spectrograms shown in Fig. 6 made. These show very clearly the widening of the absorption band as the vapor pressure increases with the heating up of the lamp.

The author wishes to express his appreciation for the valuable assistance of D. M. Lyon, George Kerr and T. J. Borsch in securing the data presented in this paper.

CHARACTERISTICS OF A NEW ULTRAVIOLET LAMP

By W. E. Forsythe, B. T. Barnes, M. A. Easley
[Lamp Development Laboratory, Incandescent Lamp Department, General Electric Company, Nela Park, Cleveland, Ohio. Received Oct. 9, 1930]

A number of different sources have been devised for the production of ultraviolet radiation. It is well known that a source that owes its radiation to its temperature alone radiates relatively a very small amount of energy in the region of short wave lengths. Thus no appreciable amount of energy for the wave-length region around 3000A is obtained from such sources unless they are operated at a very high temperature. It has been shown that a tungsten filament at the temperature of operation of some of the larger tungsten lamps gives an appreciable amount of energy in this region.[1] Arcs between carbons that are cored with salts of the rare earth metals have been shown to be very good radiators[2] for this region. The spectra obtained by the passage of an electric discharge through certain gases show energy in the wave length region around 3000A.

One of the best sources for the production of ultraviolet radiation is the mercury arc in a quartz container. The radiation from this arc extends far into the ultraviolet region with a number of lines of considerable intensity; the one at 3650A being in some instances the strongest line in the entire spectrum. When Peter Cooper-Hewitt was experimenting with a mercury arc about fifty years ago he found that if he increased the input beyond a certain amount the glass became soft and caused the lamp to fail. This led him to try fused quartz as a container for the mercury since this would stand a higher temperature than glass. When Cooper-Hewitt operated mercury arc lamps in quartz tubes the men working around these lamps were very soon complaining that their eyes troubled them. This difficulty with their eyes was very soon found to be due to radiation of short wave lengths that was transmitted by the quartz but not by ordinary glass. It seems now that the radiation shorter than about 2800A was responsible for most of the eye trouble that the men had. At that time it was not recognized that these short wave-length radiations were of any special value. As is well known it has, in the last few years, been shown that these short wave-length radiations are very valuable in many industrial operations and as a therapeutic agent in treating certain diseases.

[1] J.O.S.A. *20*, 396; 1930.
[2] Trans. I.E.S., *25*, 378; 1930.

The term ultraviolet radiation is rather broad since in general it includes all radiation between wave length 4000A and the region of x-rays. The present general interest in ultraviolet radiation is for the most part confined to those rays that are effective as a treatment for rickets and are supposed to have some value in promoting health and growth in plants and animals. There is some interest in certain rays that produce desired chemical action. Considerable work has been done on the effectiveness of radiation of different wave lengths for producing erythema, specifically the reddening of the skin that comes on some time after the exposure and persists for several hours. The relative effectiveness of the radiation of different sources in producing erythema will be discussed in a paper from this laboratory which will appear shortly. Since Peter Cooper-Hewitt brought out his mercury arc several other types have been developed. Just recently a new form of arc has been introduced and is used as the source of the radiation of the General Electric Sunlamp. This new source is a 300 watt, alternating-current tungsten mercury arc, i.e., it is a mercury arc between tungsten electrodes with the general arrangement of the electrodes and filament as shown in Fig. 1. This source is called the Type S-1 lamp.

One of the distinguishing features of this lamp is the ease of starting the arc, for it is not necessary to tilt or shake the lamp. In the bulb, in addition to several centimeters pressure of pure argon, which has a low arcing potential, there is a small amount of mercury. When the lamp is first turned on, the filament in parallel with the arc is heated to a temperature of 3000°K or more making it a good source of electrons. The dimensions of the filament and the characteristics of the transformer are such that initially there is a current of about 10 amperes through the filament and a potential of about 30 volts across it. This voltage is sufficient to start an arc under conditions such as exist in the lamp. Electrons travel between the upper ends of the filament, or more probably, from each end of the filament to the opposite electrode since that gives a shorter path with the same voltage drop. Since these electrons fall through sufficient potential difference to produce ionization of the argon, an arc is started. The bombardment of the electrodes makes them hot enough to furnish electrons for the arc. As soon as this happens the arc moves up between the electrodes and no longer plays between the upper ends of the filament.

When the arc is established between the electrodes the lamp carries about 30 amperes at about 10 volts and the filament temperature drops to 2200° or 2300°K. The change in voltage and current from the starting

condition to the operating condition of the lamp is taken care of in the design of the transformer.

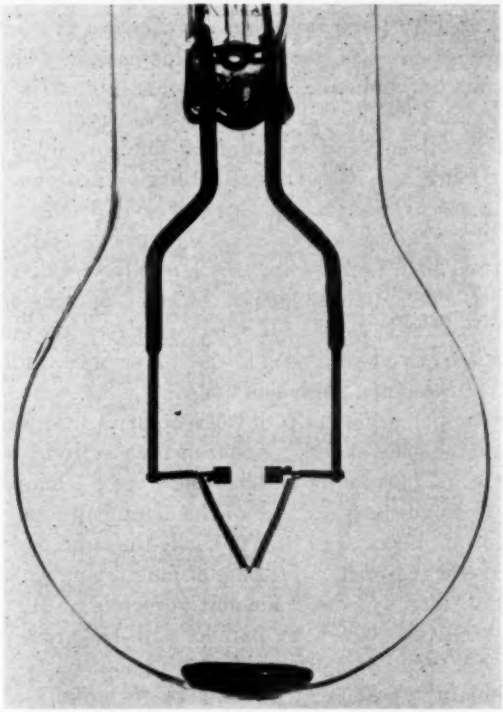

FIG. 1. *General arrangement of electrodes and filament of the Type S—1 lamp.*

A curve showing the voltage-current characteristic of the lamp is given in Fig. 2. A somewhat similar curve has been published by Benford.[3] The section *ODA* of the curve, which gives the volt-ampere relation for the tungsten filament, is followed when the arc is not operating. The line *CBP* gives the volt-ampere relation for the lamp after the arc has struck. The change from one stage of operation to the other is quite rapid. The transitions between these two curves when the arc strikes or breaks are indicated by the dotted lines *AB* and *CD*.

Since the Type S-1 lamp is intended as a source of ultraviolet radiation, it is necessary to use a special glass for the bulb. Ordinary glass

[3] F. Benford, J. Mot. Pic. Eng. *14*, 414; 1930.

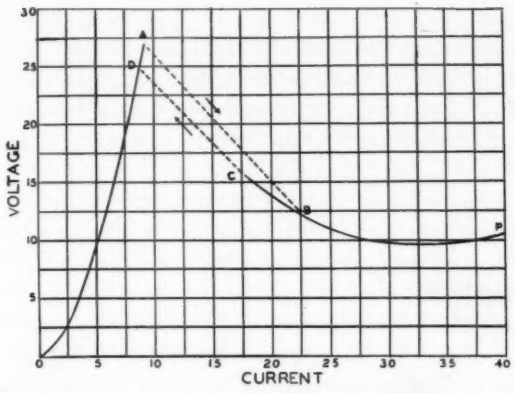

FIG. 2. *Volt-ampere curve for Type S—1 lamp. Section ODA tungsten filament characteristic followed when arc is not operating. Section PBC arc characteristic. Arc starts when point A is reached passing quickly to the operating condition indicated by point B. Arc does not break till point C is reached. Lamp voltage and current change at once to those given by point D.*

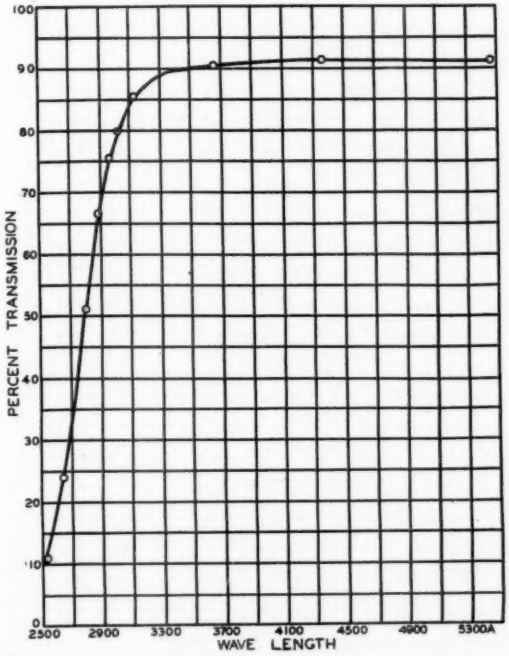

FIG. 3. *Transmission for piece 1 mm thick of special glass used for bulb of Type S—1 lamp.*

transmits practically no energy of wave lengths shorter than about 3100A. A fairly high transmission for the radiation between wave lengths 2900 and 3100A is considered especially desirable. A special glass has been found which is very satisfactory in this respect. A curve showing the transmission of a sample of this glass one millimeter thick is given in Fig. 3. This curve differs somewhat from those previously published[4,5] because for all wave lengths shorter than 3400A the bulbs of more recent manufacture have higher transmission than those on which measurements were made for the earlier articles on the Type S-1 lamp.

Using a spectrometer to separate the radiation into its component wave lengths and a thermopile connected to a sensitive galvanometer as the receiving instrument, the spectral distribution of the energy radiated from lamps of this type in a direction perpendicular to the plane of the leads has been determined.[6] The average value obtained for the intensity of each of the more important lines or groups of lines in the ultraviolet portion of the spectrum of the Type S-1 lamp is given in Table 1. These data are the averages for twenty six lamps, operating at an average current and voltage of 30.95 amperes and 10.6 volts.

TABLE 1. *Average energy flux in microwatts per cm² at one meter distance in a direction perpendicular to the plane of the leads with 115 volts on the primary of the transformer.*

Mercury lines	wave length	2537	2650	2804	2894	2967	3024	3130	3342	3650A
	$\mu w/cm^2$ at 1 m.	.09	.47	.60	.64	2.28	3.96	12.6	1.0	16.8

By correlating various data it is possible to obtain approximate values for the intensity of each ultraviolet line in the energy flux received from the lamp in the reflector. To compute the amount and distribution of the ultraviolet radiation from the Sunlamp unit, one must consider the effect of the reflector in altering the output of the lamp due to changed ventilation conditions as well as the direct effect of reflecting and concentrating the radiation. For six lamps the average temperature of the mercury pool was 293°C for operation in the open and 321°C in the reflector with the screen in place. An average of data on the effect of heating the mercury pool similar to those previously published[5] show that, for the radiation measured in a direction perpendicular to the plane of the leads the output at the higher temperature would be 43% higher at 3130A, 65% higher at 3024A, 52% higher

[4] N. T. Gordon, F. Benford, G. E. Rev., *33*, 289; 1930.
[5] W. E. Forsythe, B. T. Barnes and M. A. Easley, G. E. Rev., *33*, 359; 1930.
[6] B. T. Barnes, Phys. Rev., *36*, 1468; 1930.

at 2967A and 47% higher for the radiation below 3200A as measured by a quartz sodium photoelectric cell. For the weak lines shorter than 2967A an increase of 53%, the average value for 2967, 3024 and 3130A, is a sufficiently accurate figure. It is assumed that the same relative increases are obtained in the radiation in other directions than the one specified.

For the reflectance at each wave length an average of the value for aluminum and that for aluminum oxide powder for which curves are given by Luckiesh[7] is used in the calculations. This procedure doubtless does not give quite the correct values for the reflectance of the oxidized aluminum reflector. However, since only relative values are needed and since most of the energy flux shorter than 3200A is in a narrow wavelength region (2950 to 3150A), a rough approximation to the correct course of the reflectance curve shorter than 3200A is sufficiently accurate. The ratios of the intensities of the lines as emitted by the lamp in the reflector to those from the lamp in the open multiplied by the relative reflectances give relative values for the corresponding ratios for the intensities as radiated from the entire unit compared with those from the bare lamp. The absolute values of these ratios are obtained by multiplying by a constant whose magnitude is such that, taking account of the relative intensities of the lines, the weighted mean of the ratios is 5.4. The latter is the ratio of the intensity at one meter distance in the direct beam from the Sunlamp unit[5] to that at the same distance for the bare lamp. This is the average of data on three different lamps used in seven different reflector units. The values obtained for the ratio of the energy flux at each wave length from the unit to that from the lamp in the open and the resulting energy flux values for the complete Sunlamp are given in Table 2. The data all refer to the radia-

TABLE 2. *Computed energy flux of mercury lines in center of beam received from sunlamp unit at one meter distance from center of arc with reflector pointing downward. 115 volts on primary of transformer.*

Wave length	2537	2650	2804	2894	2967	3024	3130
Ratio to energy flux at 1 m distance along normal to plane of leads with lamp in open.	3.6	4.1	4.8	5.1	5.3	5.9	5.3
Energy flux from complete unit in microwatts/cm² at 1 m distance.	.32	1.9	2.9	3.3	12.1	23.4	67.

[7] M. Luckiesh, J.O.S.A., *19*, 1; 1929.

tion received at one meter distance from the center of the arc. The probable error in the computations outlined above is less than 5% for the lines at 3130, 3024, and 2967A for which the relative intensity at different mercury pool temperatures is known and for which the relative reflectance differs only a few percent from the weighted mean for all the radiation below 3200A. For the lines below 2967A the error might amount to 10 or 15% in some cases. Since the intensities of these lines are relatively low the probable error in the value obtained for the total energy flux below 3200A would not be over 5%.

TABLE 3. *Energy flux in microvolts per cm² in definite wave-length regions for the type S—1 lamp, the sunlamp unit, the quartz mercury arc and the sun.*

Wave-length limits	Type S—1 lamp*	Sunlamp unit*§	Quartz mercury arc* +	Sun ±
Below 2800A	0.6	2.6	37	0.0
2900–3000	2.4	12	12	0.64
2800–3100	7.7	41	34	24
2900–3200	19.3	103	70	140

* At one meter distance from center of arc.
\+ At 3.75 amperes; 72 volts on lamp; no reflector.
± Directly overhead.
§ In center of beam.

In Table 3 the energy flux in microwatts per square centimeter at a distance of one meter from the Type S-1 lamp and the corresponding computed values for the complete Sumlamp unit are given for four different wave-length regions. The values are those obtained with 115 volts on the primary of the transformer. For comparison like data for the sun[1,2] and the quartz mercury arc[8,3] are included.

It should be noted that a direct comparison of the data for the Sunlamp unit with those for the quartz mercury arc puts the latter at a disadvantage because no reflector was used with it. On the other hand the quartz mercury arc tube on account of its greater length is less suitable for concentration of the beam by a reflector than is the Type S-1 lamp and estimation of the relative outputs of complete units on the basis of data for the bare lamps would be unfair to the Sunlamp.

The curve in Fig. 4 shows the distribution of energy below 3200A from the sun that reaches the earth's surface when the sun is directly overhead. This curve was plotted from data[1] of Abbot and his associates

[8] Anderson, Fraser and Bird, J.O.S.A. *17*, 460; 1928.

and of Fabry & Buisson. The intensities of the more prominent mercury lines are shown in this same region, both for the S-1 lamp alone and for the lamp in the regular reflector. The height of the ordinate shows the intensity of the line. The solid portion of the line shows the intensity of radiation for the lamp alone and the dotted line shows the intensity of the radiation for the lamp in the reflector.[9]

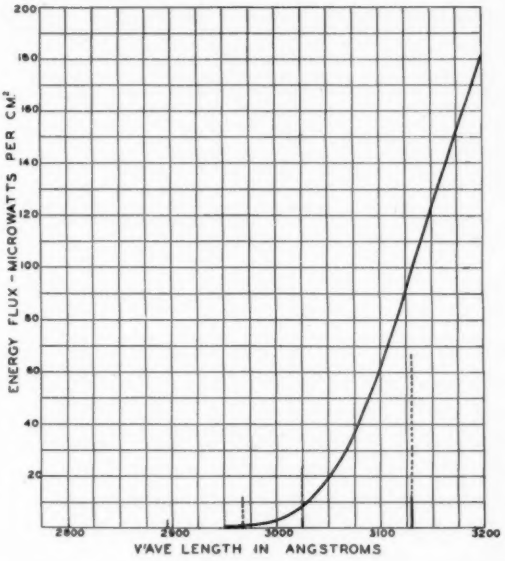

FIG. 4. *The continuous curve shows the distribution of energy below 3200A that reaches the earth's surface from the sun (ordinate: energy flux density per 100A). The heavy portion of the vertical lines shows the energy flux density of the mercury lines at a distance of one meter from the Type S—1 lamp, and the total length of the lines shows the energy flux density at a distance of one meter from the lamp in the regular reflector.*

The average temperature of the arc terminals of the Type S-1 lamp is about 3160°K and the average temperature of the filament about 2200°K. At the temperature of the filament there is less than 0.1% of the energy radiated for wave lengths shorter than 4000A and about 3% in the visible spectrum. On the other hand, at the average temperature of the arc terminals there is about 0.6% of the energy radiated in the portion of the spectrum below 4000A, and about 18.6% of the energy radiated within the visible spectrum. The arc terminals, being

[9] Compare W. W. Coblentz, J. Am. Med. Assn. *95*, 411; 1930.

at a much higher temperature than the filament, furnish most of the continuous radiation from the lamp. Continuous radiation from the arc is negligible in comparison to that from the electrodes.

The percentages of the total energy flux from the bare lamp (at one meter distance in a direction normal to the plane of the leads) in certain definite regions of the line spectrum and of the continuous spectrum are given in Table 4. These data are the average[6] for ten lamps for

TABLE 4. *Percent of total energy flux found in different wave-length regions.*

Region	Below 3200A	3200–4000A	4000–7600A	7600–17000A	Above 17000A
Continuous spectrum	.03	.22	8.8	—	—
Line spectrum	.95	.79	(1.37)*	—	—
Continuous and lines	.98	1.01	10.2	45.8	42.0

* Red lines in Hg spectrum included with continuous spectrum.

which the average current and voltage were 30.95 amperes and 10.6 volts.

In addition to measuring the radiation of the S-1 lamp by means of the spectrometer and thermopile, the radiation was also measured with a photoelectric tube connected to a sensitive galvanometer, screens being used to separate the ultraviolet radiation shorter than 3200A from the other radiations from the lamp. The photoelectric tube used (a sodium tube in quartz bulb made by R. C. Burt) is sensitive to radiation in the region 3200A to 2800A, but is also sensitive to radiation of longer wave length. It is thus necessary to use filters to limit the radiation received by the tube. One of the filters used is the Corning red-purple Corex glass which has a rather high transmission around 3000A and a low transmission in the short wave-length visible spectrum (Fig. 5). In order to separate the radiation shorter than 3200A from the longer wave-length radiation, a sheet of glass 3.2 mm thick is used. The transmission of this glass is high at 3650A and almost zero at 3130A (Fig. 5), so that when combined with the Corning red-purple Corex, only radiation of wave lengths longer than 3200A is transmitted. A measure of the ultraviolet energy shorter than 3200A can then be obtained by subtracting from the reading with only the red-purple Corex between the source and the tube the reading with both filters, the latter being corrected for the transmission of the glass screen.

The lumen output of the Type S-1 lamp was measured by comparing it in a spherical photometer with an ordinary 500-watt gas-filled tungs-

ten standard lamp. Since the light from the Type S-1 lamp is made up of two parts, that from the incandescent tungsten and that from the mercury arc, and the latter contains no lines of any appreciable strength in the red end of the spectrum; if the light intensity of the Type S-1 lamp in the red portion of the spectrum is measured, the results obtained will represent the radiation from the incandescent tungsten. The results of some measurements of temperature of the arc terminals and filament of the Type S-1 lamp showed that its average color temperature

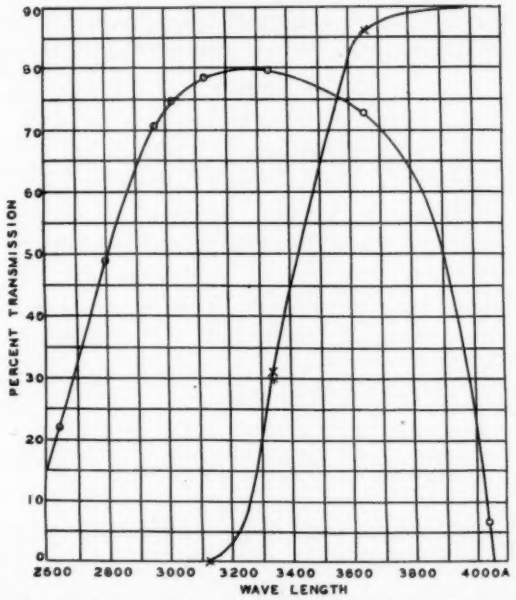

FIG. 5. *Spectral transmission of purple corex and of special glass screen.*

corresponded to about that of the ordinary 500-watt gas-filled tungsten lamp. Thus, by comparing the intensity of the light from a standard 500-watt lamp with that from a Type S-1 lamp using a red glass in the eyepiece of the photometer, results were obtained that represented the relative amount of light radiated by the 500-watt tungsten standard lamp and by the incandescent tungsten of the Type S-1 lamp. From these measurements the light from the mercury arc was found to be about 20% of the total light.

The amount of light radiated by the filament of the Type S-1 lamp was determined by starting the lamp at a low voltage and slowly

increasing it to the operating voltage and then measuring the light output of the lamp. Of course, if the lamp is started in this way, the arc does not strike and the only light is that from the filament. The temperature distribution in the filament is quite different when operated in this manner than it is when the arc is operating since the arc heats the upper turns of the filament. Thus, since the conditions under which the measurements were made were necessarily quite different from those when the arc is operating, the figure given in Table 5 for the amount of light from the filament may be slightly in error. This measurement shows that the filament takes about five amperes and gives about 100 lumens which is only about 1.7% of the total light of the lamp.

TABLE 5. *Some characteristics of the average Type S—1 Lamp.*

Distance between electrodes	5.4 mm
Current*	30.95 amp
Voltage*	10.6 volts
Light output	5670 lumens
Lamp efficiency	17.6 lumens per watt
Percentage of light from the mercury arc	20
Light from the filament	100 lumens
Maximum temperature of the electrodes	3200 deg K
Maximum temperature of the filament	2330 deg K
Temperature of mercury in lamp	285 deg C
Pressure of mercury vapor within the lamp	177 mm Hg

* The more recent type of transformer operates the lamps at a somewhat higher current and voltage than the type used for data previously published.[5]

The data given in Table 5 which are the average obtained from the measurements of a number of lamps show the characteristics of the average lamp operating in the open (without reflector) with 115 V on primary of transformer.

As was mentioned above, the arc is started by ionization of the argon present in the bulb. Very soon the heat of the filament and the arc vaporizes some of the mercury and then the arc is carried chiefly by the mercury vapor. It takes some time for the ultraviolet radiation to reach a steady state since this will not occur until the temperature of the lamp becomes steady. The curve in Fig. 6 shows the ultraviolet radiation shorter than 3200A as a function of the time after the lamp is turned on. The upper curve is for the lamp burning in its normal position; the lower is for the lamp burning with base down so that the mercury was not heated as much by the filament or arc.

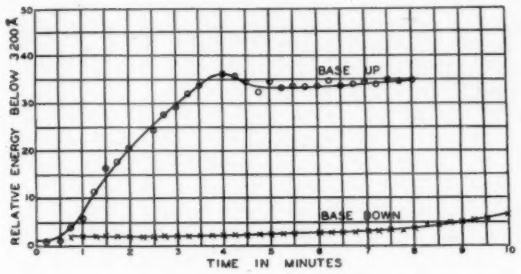

FIG. 6. *The variation of ultraviolet radiation below 3200A with the time after the lamp is turned on. The upper curve is for the lamp in the normal position with the base up and the lower curve is for the base down—115 volts applied to the primary of the transformer.*

In Fig. 7 is shown the ultraviolet radiation below 3200A as a function of the voltage applied to the primary of the transformer. Here is shown also the variation of the current through the lamp and the voltage applied to the lamp as the primary voltage is changed. In Fig. 8 are shown the relative intensities of the four strongest lines in the ultraviolet region as functions of the voltage applied to the primary of the transformer. Data on these curves (Figs. 7 and 8) show that there is a

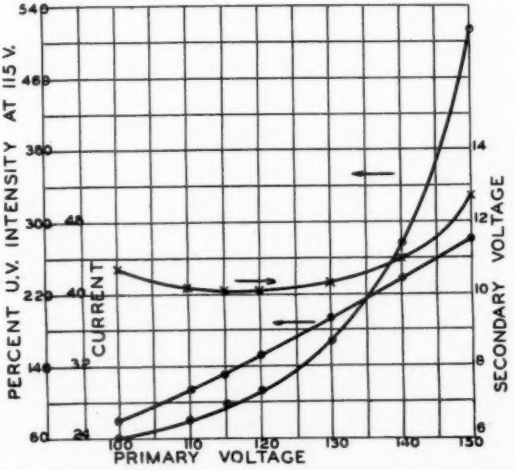

FIG. 7. *Variation of the ultraviolet radiation below 3200A with the voltage applied to the primary of the transformer, Curve 1. In Curve 2 is shown the variation of the secondary current, and in Curve 3 is shown the variation of the secondary voltage under the same conditions.*

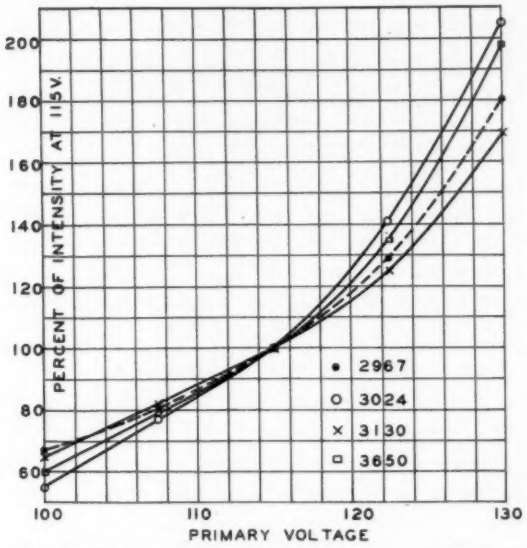

FIG. 8. *Intensity vs. primary voltage for the four strongest ultraviolet lines.*

very rapid increase in the ultraviolet energy, and especially in the lines at 3024A from this lamp as the primary voltage is increased.

The variation of the intensity of the radiation below 3200A in a horizontal plane passing through the electrodes as a lamp was rotated

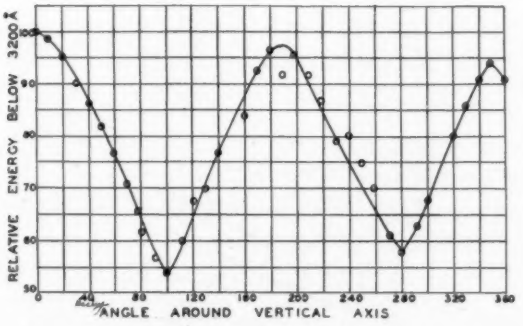

FIG. 9. *Variation of the ultraviolet radiation below 3200A as the lamp is rotated around a vertical axis. The 10° and 190° points show the relative energy in a direction from the center of the arc perpendicular to the plane of the leads with 115 volts applied to the primary of the transformer.*

about a vertical axis is shown in Fig. 9. The points at 10° and 190° represent the relative energy along a line passing through the center

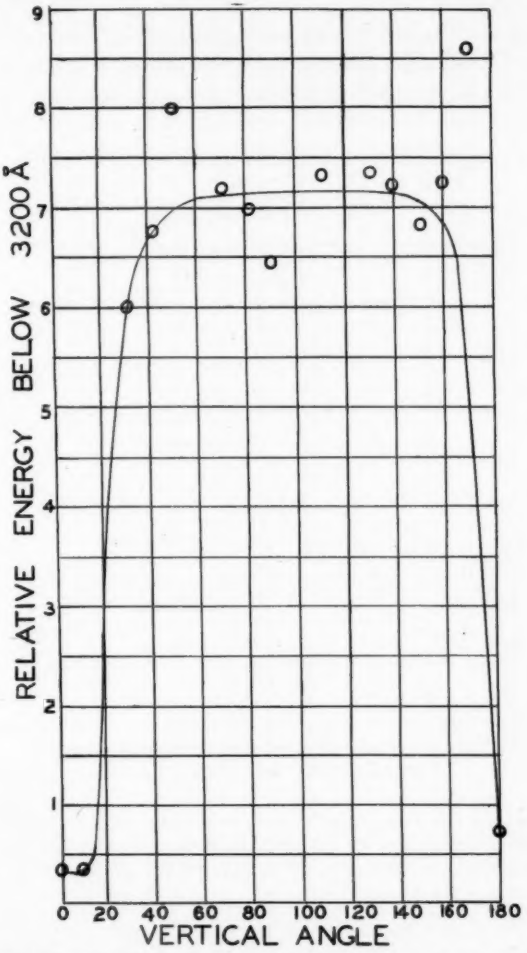

FIG. 10. *Variation of ultraviolet radiation below 3200A at one meter distance from the lamp in a plane perpendicularly bisecting the axis of the arc terminals. The zero position is directly under the lamp. 115 volts applied to the primary of the transformer.*

of the arc perpendicular to the plane of the leads, while the points at 100° and 280° represent the relative energy along a line passing through the center of both electrodes.

Fig. 10 shows the readings obtained as the photoelectric tube was rotated about a horizontal axis passing through the center of the arc. At zero degrees, where the tube was directly under the lamp, the mercury pool cut out practically all the radiation. As soon as the tube had passed beyond the shadow of the pool, the readings were approximately constant until the tube was above the base of the lamp.

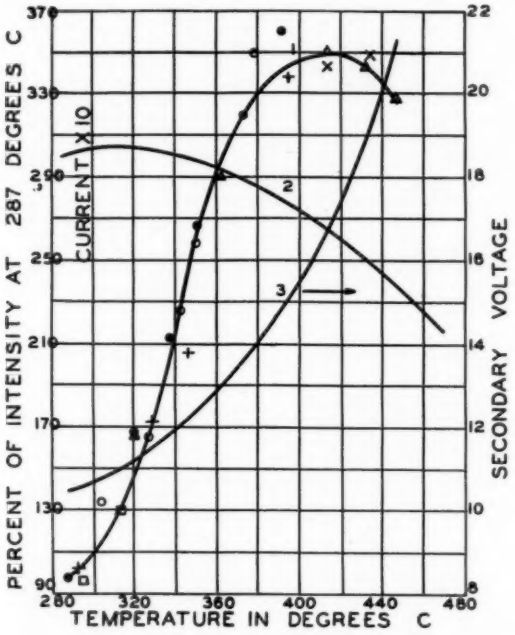

FIG. 11. *In Curve 1 is shown the variation of the ultraviolet energy below 3200A as a function of the temperature of the mercury, in Curve 2 the variation of the secondary current, and in Curve 3 the variation of the voltage across the lamp—with 115 volts applied to the primary of the transformer.*

The temperature of the mercury pool in Type S-1 lamps has been determined by means of a thermocouple threaded through a small tube sealed into the bulb, the portion of the tube containing the junction of this thermocouple being immersed in the mercury pool. It was found that for new lamps burning in the open with 115 volts on the primary of the transformer, the temperature of the mercury pool was ordinarily 270° to 300°C.

By placing a small electric heater beneath one of these lamps provided with a thermocouple, the temperature of the mercury pool could be raised at will and the effect on the operation and output of the lamp studied. Fig. 11 shows the changes in lamp voltage, current and output below 3200A as measured with a photoelectric tube when the temperature of the mercury pool was increased and the primary voltage kept constant. Fig. 12 shows corresponding data on another lamp for the radiation at four different wave lengths measured with the spectro-

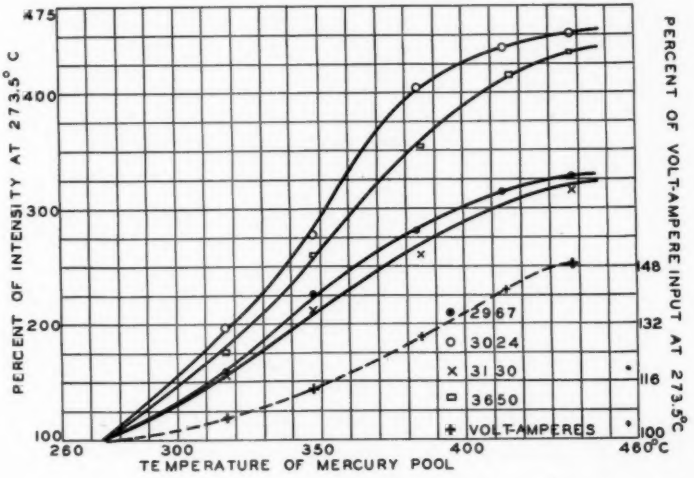

FIG. 12. *Relative intensity vs. temperature for the four strongest ultraviolet lines from the Type S—1 lamp—115 volts applied to the primary of the transformer. Relative input of lamp alone vs. temperature—scale at right.*

meter-thermopile set-up. The curve for the volt-ampere input of the lamp is included to indicate the rapid increase in the efficiency with which ultraviolet radiation is produced as the temperature is raised. The efficiency of the lamp in producing ultraviolet radiation increases somewhat faster than the square root of the mercury vapor pressure. The latter rises from 0.2 atmospheres at 279°C to approximately four atmospheres at 450°C. Increased efficiency would be accompanied by a decrease in the life of the lamp. Just as in the case of incandescent lamps, operating conditions are determined by a proper consideration of both the efficiency and the life of the lamp.

During the life of the lamp the bulb blackens considerably more than is usually the case with incandescent lamps. This is probably due chiefly to water vapor driven out of the glass on account of the high bulb temperature. By a curious set of circumstances, this blackening usually causes an increase in ultraviolet output during life. The deposit, of course, reduces the transmission of the bulb for both ultraviolet and visible light, but it absorbs sufficient energy in the infrared to raise the temperature of the bulb and the mercury pool considerably. The resulting increase in the ultraviolet output from the arc more than offsets the absorption of the black deposit.

ULTRAVIOLET SPECTROPHOTOMETRY: COMMENTS ON APPARATUS AND EXPERIMENTAL METHODS*

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ABSTRACT

A simple and satisfactory type of container for the under-water spark, with suitable electrical circuits, and a new type of quartz cell to contain the liquids under examination are described. Some points are presented concerning the use of the under-water spark and the methods of obtaining data with the quartz spectrograph and Hilger rotating sector photometer. Desirable modifications of the usual apparatus are suggested in order to increase the rapidity of the method and enhance its field of usefulness, particularly in the study of unstable solutions with varying transmissive properties.

The increasing application of ultraviolet spectrophotometry to the problems of physics and chemistry[1,2,3,4,5,6,7,8] has made it desirable to improve, wherever possible, the apparatus and methods in common use. It is our purpose to describe: (1) electrical circuits for the under-water spark which have been found satisfactory; (2) a container of new design for the under-water spark, and (3) a new type of quartz absorption cell for use in the examination of liquids. We shall call attention to certain important points concerning the design and use of the under-water spark, with the quartz spectrograph and Hilger rotating sector photometer, the methods of obtaining data from the photographic plates and desirable modifications of the apparatus to permit greater speed in obtaining the spectrograms. The new designs of apparatus were worked out during the course of certain experiments on bile pigment commenced during the latter part of 1927.

Electrical Circuits for the Under-water Spark

The circuits to be described are similar to those employed by Howe,[6] so far as general arrangement is concerned. But the details of construction and of operation may be of interest to those who wish to construct such circuits, since it is somewhat difficult to predict the results which an untried circuit will give with the under-water spark. The following

* Abridgment of a portion of thesis submitted by George E. Davis to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the degree of Ph.D. in Biophysics.

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circuits have been very satisfactory in connection with an under-water spark gap from 12 to 18 mm in length, used as source of radiation, with the quartz spectrograph and Hilger rotating sector photometer.

In Fig. 1, R is a 110 volt, 2.5 kilowatt Thordarson transformer,

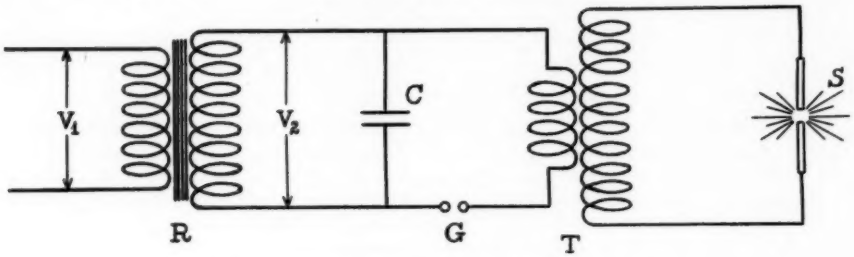

FIG. 1. *Electrical connections for under-water spark.*

supplied with 60-cycle current under a potential difference V_1 of about 97 volts. Current from the secondary, at about 17,600 volts V_2, passes to capacity C and to the primary of the Tesla coil T. C consists of three Thordarson condensers in parallel, with a combined capacity of 0.027 microfarad. The condenser plates are of aluminum with rolled edges, immersed in oil and separated by thick mica plates. Discharge through the primary of T occurs at breakdown of the spark gap G. For the latter a radio quenched spark gap with 19 sections was used. As compared to the open gap, this type has the decided advantage of not producing objectionable gases (ozone and oxides of nitrogen). Also it is quiet and steady in operation and does not require an air blast or moving parts. Its breakdown potential can easily be varied by removing or inserting spark gap sections. The Tesla coil T was built according to suggestions made by Prof. R. C. Gibbs of Cornell University. The secondary consists of 180 turns of insulated No. 18 copper wire wound on a wooden core about 53 cm long and 29 cm in diameter. The primary is formed of 8 turns of heavy wire wound on a wooden ring 39 cm in diameter and 11 cm wide surrounding the secondary coil at its midpoint.

This arrangment provided ample electrical energy at the spark gap S. The voltage was sufficient to ensure a continuous succession of sparks with the terminals separated any distance to about 18 mm using distilled water of ordinary purity (single distillation). With greater separation of the terminals the spark refused to pass or was inconstant in action. Unless the water is fairly pure it is difficult to obtain a disruptive discharge with the terminals only a few millimeters apart.

UNDER-WATER SPARK GAP AND CONTAINER

Various types of containers were tried and discarded before a device was evolved that was satisfactory in every way. The design finally adopted is much simpler than the one described by McNicholas.[9] Although the latter provides for somewhat more rapid adjustment of the length and position of the spark gap, such adjustments need be made only infrequently and can be carried out readily on the type of container we are to describe. This container has been in use for more than a year and has proved to be very satisfactory.

The construction is shown in detail in Fig. 2. The walls of the container are built of 0.5 in. sheets of hard rubber held together by screws.* The joints are made water-tight by strips of thin rubber dam (dental) placed between adjacent surfaces and fastened to one surface with rubber cement. The rubber dam was found to be more satisfactory than cement alone, the joints remaining perfectly water-tight after a long period of use (more than a year). Thicker rubber was used under the front plate of the box to avoid tearing the rubber when it was necessary to remove the front of the container.

The electrodes T are of tungsten, approximately 2 mm in diameter. They are brazed to brass rods A and B, with which electrical connections are made from the Tesla coil. These rods pass through hard rubber rods C and D, 2.2 cm in diameter and about 10.5 cm long. The tungsten electrode fits the hole closely from point P to the tapered end of C and of D. From P to the outer end, the hole is a little larger than the brass rod. The holes are filled with hot De Khotinsky cement before the metal rods are inserted, thus sealing the holes and holding the rods firmly in position. Leakage around the hard rubber rods is prevented by rings R, R with soft rubber gaskets underneath. The gaskets are set in circular grooves in the end plates and are forced against C and D by the screws which pass through the rings. This device holds C and D firmly in place and allows for ready adjustment of the length and vertical position of the spark gap. Special provision for lateral adjustment is unnecessary, as the entire apparatus with its support may easily be moved and, once in the proper position, permanently clamped to the table. The tungsten electrodes are set about 12 mm apart. With use they slowly waste away, so must be adjusted occasionally.

* While this thickness of wall proved satisfactory, it perhaps would be well to use thicker sheet in order to increase the factor of safety. A second container was built of 0.5 in. sheets of cloth-fabricated bakelite.

A window W of polished quartz about 1.5 mm thick covers a 10 by 24 mm opening in the front of the box. The window is held against a sheet of soft rubber by four screws with rubber washers. The screws pass through holes drilled through the quartz plate. This method of holding the window was found to be satisfactory, the soft rubber preventing the shock of the electrical discharge from breaking the thin sheet of quartz

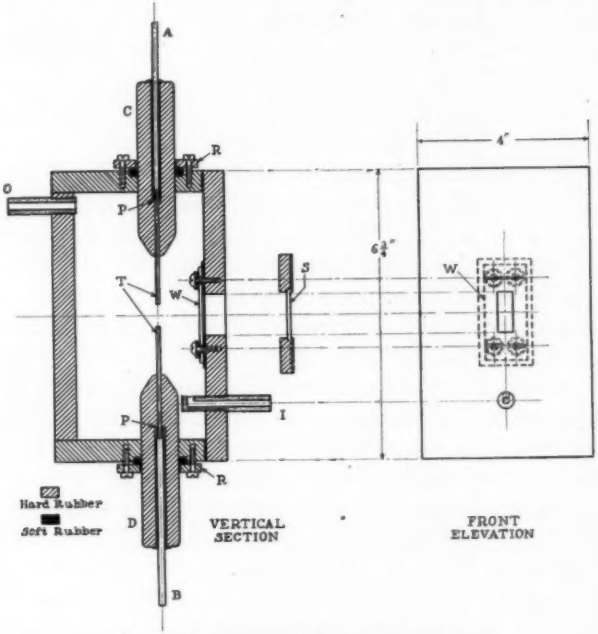

FIG. 2. *Under-water spark gap and container.*

even though the spark gap is within 2.5 cm of it. The window of another container, subsequently constructed, was held against the soft rubber by bone cleats at the sides. This device made it unnecessary to drill through the quartz plates. Whether it would prove satisfactory over a long period of use has not been determined. Radiation from the spark falls on a thin sheet of ground quartz S, which serves as a source of more uniform intensity than the spark itself. Without this diffusing screen the spectrograms were less uniform and satisfactory, even with the most careful alignment of the spark gap. The screen tends to smooth out the effect of occasional lack of uniformity occurring in the spark discharge.

Distilled water from an elevated reservoir of large capacity is led into the container at *I* and out at *O*. The outlet is so placed that an air cushion is left at the top of the container. This cushion serves to lessen the shock of the disruptive discharge. The flow of water may be regulated by a screw clamp on the rubber tube leading to the inlet. The water becomes impure with use and must be changed at regular intervals. With a spark gap of about 12 mm, a maximum of about fifteen photographic exposures of six seconds each can be made for each liter of water used.

Certain features in the design of the container deserve special mention. In an earlier model the electrodes were placed in the center of the container (a cylindrical one), the window was fastened to the outside surface of the wall, leaving a shallow recess on the inner side, and both inlet and outlet for water were located at the back. With this arrangement of parts the illumination of the screen *S* varied in distribution, so that the relative intensities of the upper and lower beams passing to the spectrograph were not constant. As a result it was impossible to trace the spectral transmission curves with certainty. It was observed that some of the small gas bubbles formed by the electrical discharge tended to collect at the quartz window, where they circulated about, apparently unable to escape readily from the shallow recess formed by the wall of the container. These bubbles were held to be chiefly responsible for the fluctuations in the light passing through the window. To prevent them from collecting, the window was mounted as shown in Fig. 2, so that no recess was formed on the inner side. At the same time the spark gap was moved nearer to the window so that the convection currents formed by the heated water and by the gas bubbles would tend to move upward past the window. Also, the inlet tube was moved to the front of the box so as to direct the stream upward past the window. With these changes in design the undesirable fluctuations of the light were eliminated and uniformly good results were obtained.

The container may be supported in any convenient manner while it is in use. In our work the container was fastened to a wooden panel sliding in vertical guides on a wooden support built somewhat like a box with front and top removed. The panel carried a millimeter scale at the edge to indicate vertical height and could be clamped in any position. The wooden support was clamped to the table which supported the spectrograph and sector photometer. This simple mounting for the spark gap container proved to be entirely adequate.

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QUARTZ ABSORPTION CELL

Often it is desirable to examine thin films of liquid. The following construction of cell was found to be simple and satisfactory for films thin enought to be retained between quartz plates by capillarity.

Two rectangular quartz plates Q, Fig. 3, with accurately plane-polished faces were clamped together with a thin glass spacer G placed between them at one end. The plates measured 25 by 75 mm and were 1.5 mm thick. The glass spacer was a microscope cover glass measuring 25 by 40 mm and about 0.1 mm thick. For convenience in handling, it

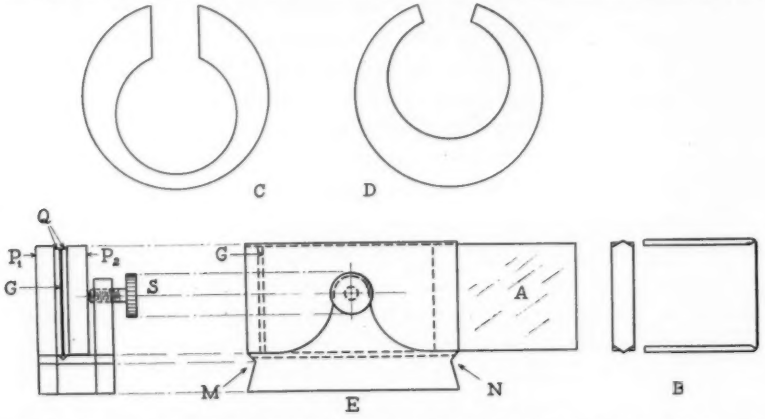

FIG. 3. *Lower figures, construction of thin quartz cells. C, D, glass spacers for thicker cells.*

was cemented to one of the quartz plates with a half-and-half mixture of beeswax and rosin so as to cover a little more than half of the plate. The clamp was formed by a fixed brass plate P_1 and a movable plate P_2 actuated by a screw S. The clamp with the quartz plates and spacer in position could be mounted quickly by inserting the edge E into a slot in a metal support, where it was held by a spring catch by means of the notches M and N. The liquid was held between the quartz plates at A by capillarity. If air bubbles were left between the plates when the liquid was run in, they were swept out by means of a fine thread, preferably of glass. Evaporation from the edges of the film was for the most part eliminated by slipping light aluminum covers over the edges of the slides. The covers were made by bending thin strips into the shape shown at B.

The thickness of the space between the free ends of the quartz plates was measured by means of a micrometer microscope. Readings were

taken at several points around the edge and averaged. In constructing a thin cell it should be remembered that the negative logarithm of the fraction of light transmitted is proportional to the thickness of transmitting substance. Therefore, if accurate relations between spectral transmission and thickness of solution are to be determined, variations in the thickness of the cell should be relatively small. Otherwise it is not allowable to take the average thickness as the effective thickness of the solution.

Thicker cells were made by clamping circular quartz plates (the circular shape is immaterial) against opposite sides of glass spacers shaped as shown at *C* and *D*. The quartz plates had parallel flat polished surfaces. The surfaces of the spacers were ground flat and parallel, then rubbed with a little paraffin and the excess scraped off. *C* is the spacer for the upper cell and *D* for the lower cell. Holders (not shown) were constructed of 1/8 inch brass plates. They consisted essentially of two leaves, one fixed and one hinged, between which the quartz plates, with glass spacer between, were held by the pressure exerted by springs passing from one leaf to the other. A circular opening was cut in each leaf, corresponding to that in the spacer, so that the radiation could pass through the cell. Each holder was provided with a flange like that shown at *E*, so as to fit into the same supporting device used for the thin cells.

NOTES ON EXPERIMENTAL METHOD

Accurate adjustment of the height of the under-water spark is important when this device is used with the quartz spectrograph* and rotating sector photometer. The correct height may be determined by making a series of test exposures with the quartz cells empty (or removed), changing the height of the spark by 0.5 mm steps. We found that even with such small changes in height, the corresponding successive changes in relative intensity of darkening of the adjacent spectrograms could easily be seen. Therefore it is evident that accurate vertical adjustment of the spark gap is essential to accurate results. It is felt that this point has not been fully appreciated in some of the quantitative measurements that have been made heretofore. The importance of accurate

* Reference is made to the usual form of spectrograph in which the absorption spectrum of the substance under examination is photographed in juxtaposition with the absorption spectrum of a comparison substance (the solute, in case of a solution) and points of equal intensity of darkening taken as corresponding to transmission ratios indicated by the sector photometer (or equivalent device). Quartz spectrograph E316, built by Adam Hilger, is such an instrument.

spark adjustment was pointed out by Howe, who used a horizontal spark gap. Substitution of the vertical gap has greatly lessened the difficulty of securing satisfactory spectrograms. But even with the vertical spark gap, accuracy of adjustment is of first importance.

Wasting away of the electrodes necessitates only occasional retesting of the height of the spark. In this respect the under-water spark has a decided advantage over the ordinary form of arc, since the terminals of the latter waste away much more rapidly.

The position (wave length) of a point of maximal or minimal transmission usually can be determined more accurately by examination of the photographic plate than by drawing the absorption curve which, from the positions of the plotted points, appears most probable in that region. It seldom happens that the transmission at a maximal or minimal point is close enough to any one of the predetermined values of transmission through the comparison substance to give the appearance of equal blackening of the adjacent spectrograms. Therefore, in general, we have two successive exposures, in one of which the spectrogram of the comparison substance is not dark enough for a match at the maximum or minimum, while in the other exposure it is too dark. In the one exposure we may locate the wave length at which the adjacent spectrograms most nearly match, while in the other we may find the wave length at which the spectrograms appear to differ most. With the under-water spark as source of radiation and using the usual type of photographic plate, these two observed values of wave length ordinarily are not the same, especially when the transmission or absorption band is broad and not especially prominent. Therefore, to estimate the true position of the maximum or minimum, both values should be observed and averaged, weighting the values according to the nearness of the transmission value to that of each of the two adjacent comparison spectrograms. The two observed values usually are not the same because of the fact that the intensity of blackening of the spectrograms, unmodified by absorbing substances placed in the paths of the beams of light, increases as one passes from the region of short wave length to that of the longer wave lengths, except in one region of the visible spectrum. Because of this, differences in intensity of darkening in adjacent spectrograms are more noticeable in the shorter wave lengths, and in general the effect is to cause points of greatest contrast to appear to be shifted toward the shorter wave lengths while points of greatest similarity appear shifted in the opposite direction.

It is necessary frequently to estimate values of transmission at points at which equal darkening of the adjacent spectrograms does not occur. This is usually the case at maxima and minima. Often at other points the shape of the curve is not well defined except by supplementing the values of transmission at match points by values estimated at other positions. In making such estimations it must be remembered that equal contrasts on the photographic plate do not necessarily represent equal differences in intensity of illumination. The slope of the intensity-darkening curve decreases as the intensity increases, at least above very small intensity values. This should be taken into account in comparing the darkening of the spectrogram in question with that of each of the adjacent comparison spectrograms, next lower and next higher in transmission, especially when the steps between successive intensities of the comparison spectrograms are large. Obviously in making such comparisons it is advantageous to have the darkening of the comparison spectrograms increase or decrease regularly as the transmission of the variable sectors of the photometer is made progressively larger or smaller. This will be the case if only the size of the sector openings is varied from one exposure to the next. Therefore the spark should be operated for the same length of time for all the exposures. For the same reason the spark discharge should be kept as nearly as possible an unvarying source of radiation throughout the series of exposures.

Many solutions undergo rapid chemical or physical changes on standing or on exposure to certain agencies such as heat and radiation. Clearly the absorption curve obtained for such a solution cannot be correct unless the time required for obtaining the data is less than that required for the occurrence of noticeable changes in the transmissive properties. Undoubtedly great scientific value would attach to any method which would enable us to obtain correct absorption curves for such solutions.* Such a method would make it possible to follow the chemical or physical changes by means of the corresponding progressive changes in the absorption spectra. Observations of this nature would be extremely useful in the study of biological fluids.

* A rapid recording spectrophotometer for measuring the color of a reflecting surface has been designed. See A. C. Hardy, *A Recording Photoelectric Color Analyser*, J.O.S.A. and R.S.I., *18*, 96–117; 1929. Hardy's apparatus may be used for measurements on transmission in the visible spectrum as well as for reflection. Rapidly operating photoelectric spectrophotometers are described by Ellsworth and others, Oil and Fat Industries, *7*, 15–19; 1930, and by Mulder and Rasek, J.O.S.A., *20*, 155–156; 1930, and Textile World, February, 1930.

In spite of its high accuracy, and other commendable features, the quartz spectrograph (of the usual type represented by the Hilger spectrograph E316) with rotating sector photometer is wholly unable to cope with rapid changes in the transmissive properties of the substance under examination. As a rule, about sixteen exposures are required for the accurate determination of an absorption curve, and frequently twice that number are required. Under the best working conditions, a minimal time of about eight minutes is required for sixteen exposures (on a single plate) or eighteen minutes for thirty-two exposures (on two plates). This precludes the possibility of obtaining the absorption curve of a solution which is rapidly fading or otherwise changing in its ability to transmit radiation.

However, it should be possible to modify the apparatus so as to allow much greater speed in obtaining data by this method without sacrifice of accuracy. Of the total amount of time required for obtaining a series of spectrograms, by far the greater part is used in adjusting the photometer sectors and the plate holder. With the under-water spark and accessories described in this paper, five or six seconds of spark operation was found to be sufficient for a single photographic exposure, except for values of transmission as low as 1 or 2 percent.* Considering all transmission values from 1 to 100 percent and with an intense under-water spark as source of radiation, the average time of spark operation for a single exposure need not exceed five seconds. This time is small compared to that required for resetting the sector photometer and plate holder, for these operations require twenty-five to thirty seconds under the best conditions. Therefore it is evident that we can increase the speed of the method most effectively by reducing the time required for the necessary adjustments of the photometer and plate holder. It is suggested that these adjustments should be made automatic. In that which follows we shall describe briefly the essential features which seem desirable in such a mechanism and shall suggest some suitable details of construction.

The photometer sectors should be capable of accurate adjustment while in motion, as are those of certain photometers now in use. Settings should be controlled by a series of stops whose positions can be prearranged. These stops may be released in their proper order electro-

* A considerable range in intensity of darkening of the comparison spectrograms (beam through solvent) results if the same time of spark operation is used for all transmission values, of course. Usually this presents no difficulties and frequently less time is required than in attempting to secure equal blackening of all the comparison spectrograms.

magnetically or by a clock mechanism. In case the photometer settings are made by rotating a graduated head, a constant torque may be applied to the head by a motor-driven friction disk, so that when a stop is released the head is turned to its next position.

It should be unnecessary to change photographic plates while obtaining data for a single absorption curve, whether many or few exposures are required. Therefore both wide and narrow plates should be available, with plate holder (or holders) built to accommodate the various widths. If plates wide enough to accommodate thirty or more exposures are objectionable, it should be possible to lay two or more narrow plates side by side in the same plate holder.

The plate holder should be so mounted as to move easily and without "play" under the action of its own weight. Its settings may then be controlled by a series of stops in prearranged positions, the stops being released in consecutive order by a clock mechanism or electromagnetically.

A shutter should be arranged so as to close automatically and interrupt the exposure during resettings of the sector photometer and plate holder. Or the same effect should be accomplished by the automatic breaking of the current supply to the source of radiation.

With automatic adjustments operating essentially as described, it seems that each photographic exposure and subsequent resetting of the plate holder and photometer could be accomplished in eight seconds or less. Thus the time required to obtain sixteen exposures for an obsorption curve would be reduced from about eight or nine minutes to approximately two minutes.

If only a single absorption curve is to be determined, exposure of the wave-length scale (or standard line spectrum) can be made at leisure after the run. But if a series of curves is required, as in following the chemical or physical changes of an unstable solution, exposure of the wave-length scale must be made before changing plates. With proper provision for rapid plate changing, it should be possible to make two exposures of the wave-length scale and change plates in thirty seconds or less. Thus for a series of absorption curves for the same specimen, about half a minute must be added for these operations, making the time for each curve about two and a half minutes (sixteen exposures) or four and a half minutes (thirty-two exposures). The reductions in time here represented would greatly enlarge the field of applicability of the method, particularly along the lines we have indicated, without any sacrifice of the high accuracy now attainable.

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A NEW PHOTOGRAPHIC EFFECT

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Introduction

It seems well established by experiment that the latent image is formed about sensitivity centers as nuclei in the silver halide grain. These nuclei may be either grouped about specks of foreign matter upon the surface of the halide crystal or even within the crystal[1] or they may be found upon the edges and corners of tabular, polyhedral grains. Trivelli and Sheppard[2] have shown that in specially prepared silver bromide crystals the photochemical darkening occurs in definitely oriented patterns depending upon the structure of the crystal. The same authors, however, found that in commercial emulsions the visible darkening under the microscope was very irregular and patchy. Most of the patches were unresolved as discrete centers. In the case of the larger grains the darkening took place in a discontinuous ring inside the unaffected edge or as dark blots on the edge.

It appears to the writer that the work referred to above is digging into the very heart of the problem of the latent image formation. The beautiful patterns obtained by Trivelli and Sheppard in the visible decomposition of their specially prepared crystals show beyond question that there are varying degrees of susceptibility in the different regions of the crystal. They advance the idea that along certain lines in the crystal the electronic orbits are deformed. It is not clear, however, how the deformation of electronic orbits can cause the molecule to be more easily decomposed by the radiation, since the ejection of an electron does not necessarily mean the decomposition or breaking up of a molecule.

Let us approach the problem from a different angle. Suppose we assume that radiation sets up vibrations in or between the atoms and molecules just as we do in the heating effect of radiation. It is conceivable that the crystal lattice may be partially or completely broken down by these vibrations. The idea of a photo-mechanical disintegration of crystals is not new. S. E. Sheppard and W. Vanselow[3] discuss the prob-

[1] S. E.Sheppard—A. P. H. Trivelli and R. P. Loveland—J. Franklin Inst. *200*, 51; 1925, also W. Clark and F. C. Toy, Phil. Mag., *44*, 352; 1922.

[2] A. P. H. Trivelli and S. E. Sheppard, J. of Phys. Chem. *27*, 1568; 1925.

[3] S. E. Sheppard and W. Vanselow, J. Phys. Chem. *33*, 250–273; 1929.

lem and give a number of important references. They say in particular —p. 261 of their paper,–

"In view of the problem of disposing of the lattice energy in heteropolar lattices of relatively rigid ions, it appears that the evidence for direct (primary) photomechanical disintegration of the silver halides may have to be reconsidered."

It has been suggested by A. P. H. Trivelli and S. E. Sheppard[4] that there are lines of strain in the crystal. If this is true, then the freedom of vibration of the molecules along these lines of strain must be different and we could well expect the patterns obtained by Trivelli and Sheppard[5] in their large crystals. Sharp corners, specks of foreign matter, flaws and faults might be expected to give us regions of varying degrees of strain. Thus we may place the sensitivity center on a physical basis.

There is but little doubt that the disturbance in a crystal must reach a certain stage before it becomes developable and further, that one developable nucleus will render the whole grain subject to development.[6] Let us, then, attempt to picture the situation from the point of view of a primary photomechanical disintegration of the silver halide.

We will suppose that a single molecule in a crystal is so situated that it may respond with disruptive violence under the influence of the onfalling radiation. It is inconceivable that a molecule even in the outermost region of a crystal lattice could be torn asunder without influencing its immediate neighbors. New strains would necessarily arise causing other molecules to become susceptible to the shaking, disruptive influence of the radiation. If the radiation is of sufficiently low intensity to cause a mild disruption of the susceptible molecule, then the spreading of the strain among the nearby molecules would be slight and we would expect the results of Channon[7] that light of feeble intensity produces a low photographic density which cannot be increased by increasing the exposure time. That is, the centers susceptible to the feeble radiation can be exhausted. This appears to fit in with the experimental facts better than ascribing the phenomenon wholly to reversal as Channon did. Reversal, however, probably plays a secondary part as will be discussed a little farther on.

Now, as the intensity of the radiation increases not only are more primary centers affected, but the violence of the disruptions are aug-

[4] The Silver Bromide Grain, p. 121, 1921.
[5] Loc. cit.
[6] Silberstein, Phil. Mag. *5*, 464; 1928.
[7] H. J. Channon, Phot. J. *45*, 164; 1920.

mented causing a more rapid spreading of the "disease" among the neighbors. Therefore, the characteristic curves would take on steeper slopes as the intensity of the radiation is increased which is a well known experimental fact.

As the compactness of a disrupted region increases rearrangements and recombinations would become probable, giving reversal. We would, therefore, expect the two kinds of failure of the so-called reciprocity law as found by Jones, Huse and Hall.[9] That is, we would expect the efficiency of the radiation to increase with the intensity up to the point where the favorable effect of the violence of the disruption of the molecules is balanced by the reversal. Beyond this optimum intensity, the reversal would bring about the failure of the second kind. That is, the reciprocity law states that the photographic density is proportional to the exposure E where $E=It$, I being the intensity of the radiation and t, being the time of exposure. In the well-known Schwarzschild equation $E=It^p$, it is found[9] that p is not only a function of the intensity but depends upon the emulsion, the development factors, etc. Below the optimum intensity referred to above, however, p is less than 1; beyond, it is greater than 1 and at the optimum intensity it is equal to 1, or, in other words, the reciprocity law holds only in the limited region of the optimum intensity for a given exposure In the region below the optimum intensity the photographic blackening is greater than would be calculated on the reciprocity law basis while above this optimum intensity, the blackening is less. That is, we have two kinds of reciprocity law failure—one in which the blackening is too great and one in which it is too small.

E. Kron[10] has done some important work in this region of optimum intensity. An interesting and enlightening discussion of the Kron effect is given in a monograph by F. E. Ross.[11] On page 65, of this book we find:

"According to Kron, therefore, there is an intensity most economical of energy in producing any given photographic effect."

Two sentences farther on we find:

"That there should be an optimal intensity is indeed a remarkable

[8] L. A. Jones, E. Huse and V. C. Hall, J.O.S.A. and R.S.I., *12*, 321; 1926.

[9] See the work of Jones, Huse and Hall, loc. cit.

[10] E. Kron, Jarhb. Photo. 2816; 1914.

[11] The Physics of the Developed Photographic Image, Eastman Kodak Company, Rochester, New York; 1924.

fact, the physical interpretation of which is at the present time beyond us."

It seems to the writer that this primary photomechanical hypothesis together with the idea of recombination furnish a satisfactory physical basis for this optimal intensity as pointed out above. Quoting from the monograph by Ross, page 66, we find:

"It may accordingly be inferred that the relative velocities of development must be different in the two cases, depending on whether the images are formed by strong or weak light respectively. This effect, which is analogous to a generalized Purkinje phenomenon, may appropriately be called the Kron effect."

It seems to the writer that this is in accord with the photomechanical disintegration idea. That the silver halide crystals are enlarged and silver extruded to considerable distances through the gelatin during exposure was noted by A. P. H. Trivelli and S. E. Sheppard.[12] Quoting from their paper page 1573, we have:

"A remarkable observation on the visible decomposition of a special emulsion may be mentioned, which is figured in Fig. 4. As will be seen, the larger grains labelled "unexposed" already show beginning of decomposition. Specially noteworthy, however, is the way in which spurs of silver have been thrust out from the grains, and the general expansion of the grains on prolonged exposure. If the great strength of dry gelatin which has a tenacity of 1200 lbs. to square inch, is borne in mind, it is evident that tremendous force has been exerted in extruding these jets of metal. As might be expected, photographs by polarized light showed very marked strains in the gelatin about those grains. Such effects were not observed with any other emulsion."

It is indeed remarkable that such visible effects could be obtained. A physical disintegration, however, of the crystal lattice whether visible or invisible, might well be expected to affect the rate of development.

The Clayden[13] effect seems to fit in also with this primary photomechanical disintegration hypothesis. In a sharp impact of light—short flash—only those molecules most favorably situated to respond to the radiation are affected. The violent disruption of these, however, is sufficient to permit rearrangements while the less favorably situated centers are not brought up to developability. Therefore, on subsequent exposure, we find a certain amount of reversal in the region previously exposed to the bright flash.

[12] J. Phys. Chem. *29*, 1568–1582; 1925.
[13] R. W. Wood, Astrophys J. *17*, 361; 1903.

It has been known for many years that agents other than radiation may leave their imprint on a photographic film or plate. Some chemical agents as hydrogen peroxide render a photographic emulsion developable. Other chemical agents such as chromic acid, render an emulsion less sensitive to light. Mechanical scratches as lines drawn by a rounded point stylus are developable. In a dissertation by M. Volmer[14] some experiments are described wherein an impression was made upon a photographic plate by drawing fine lines with rounded end of a glass rod. He referred to this as a pressure effect. By successive application of different agents for blackening the photographic film, he reached the conclusion (page 42 of his paper) that the slopes of the blackening curves of pressure, x-rays, intermittent light impacts—light from electric sparks—and continuous illumination decrease in the order named.

Warnercke[15] seems to have been the first one to note the effect of writing on a photographic film with a rounded glass rod. On page 11 of the paper referred to above Volmer says that Warnercke found by writing on a gelatine film with a rounded glass rod using gentle pressure so as not to scratch the film, that these marks developed out black. If, however, the plate was fogged with daylight before developing, then the marks came out white on a dark background. By reversing the procedure, the writing came out darker than the background. This so-called shearing pressure effect described by Warnercke and by Volmer is obviously not a true pressure effect, since no pressure was applied during exposure. The silver halide crystals were mechanically disintegrated along the line drawn by the glass rod; the fact that these lines were developable supports the photomechanical disintegration hypothesis. Any agent, mechanical or chemical, which breaks up the crystals of the silver halide should produce developable centers.

It was found in the research to be described below that the application of pressure to a photographic emulsion prevents the formation of a latent image to a remarkably large extent. While this experiment is no better than those mentioned above in support of a photomechanical hypothesis yet it is very direct, since there is little doubt that high pressures should tend to prevent such a disintegration. It is certainly difficult to see how a shaking up or the ejection of electrons or the setting up of photo-conduction currents[16] can serve as a physical basis for the pressure effect found.

[14] M. Volmer, Phot. Umkehrungserscheinungen Treang. Diss. Leipzig; 1910.
[15] Phot. Archiv. 120; 1881.
[16] A. P. H. Trivelli Phot. J. *68*, 67–72; 1928.

The idea of a direct (primary) photomechanical disintegration is far reaching in its scope. The spectral region, 4000 to 6000A, effective in the formation of the latent image in the emulsions used in this experiment, is commonly ascribed to the atom both as to emission and absorption. Our modern theories give us no satisfactory physical basis either of the origin of frequency in radiation, or of the mechanism by means of which the absorption of radiation may set up atomic or molecular vibrations. In order to tie up radiation with atomic and molecular vibrations, it seems necessary to make some new fundamental assumptions as to matter and radiation.

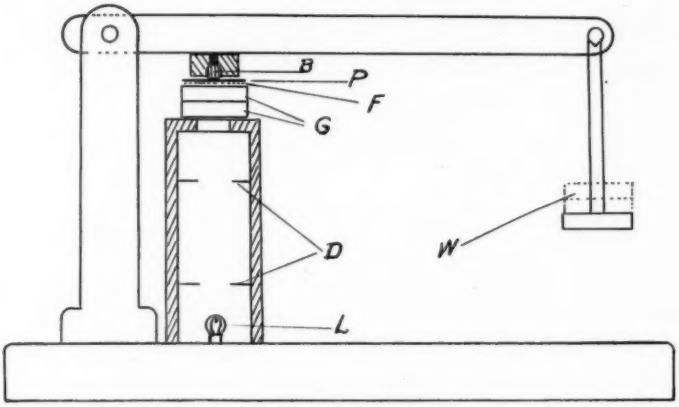

FIG. 1. *Diagram of the apparatus.*

In 1925 the writer formulated an hypothesis of matter and radiation which has led to a series of experiments one of which is described in this paper. It is postulated in these speculations that light is a wave in the gravitational field of matter originating in the elastic segmental vibrations of the atoms and molecules. These speculations are leading to new experimental data and it is hoped that they may provide the way for a better understanding of matter and radiation.

APPARATUS

The apparatus used is shown diagramatically in Fig. 1. When photographic paper, P, is used, it is placed on top of the plate glass, G, with the film side, F, next to the glass. The pressure is applied by means of a lever and weights, W, which force the flattened side of a steel ball, B, against the back of the paper P, The source of light, L,

is a number 35 mazda lamp, the filament of which is 29 cm from the film. The light is confined to a beam by means of the two diaphragms, *D*. The beam of light was circular in cross section having a diameter of 1.6 cm while the flattened fraction of the ball had a diameter of .55 cm and was approximately concentric with the beam.

In the case of photographic plates, the film side was placed next to the steel ball. Most of the exposures were made for 30 seconds with a stop watch, using a filament current of .55 to .6 ampere for both plates and papers, the filament being rated at .8 ampere.

The photometer used consists of two photoelectric cells connected in as two arms of a Wheatstone's bridge, the other arms being two 100 volt edison batteries, as described by F. K. Richtmyer.[17] A Compton Electrometer, set at a sensitivity of 2000 to 4000 scale divisions per volt, serves as a balancing instrument. Light from a fixed lamp passes through the film to be measured into one of the cells. The light from the movable lamp passes into the other cell. The different settings of the movable lamp for zero electrometric reading enables one to calculate the relative densities with a high degree of accuracy. The two lamps were as nearly identical as could be obtained and were in series with each other. The Hurter and Driffield definition of density is used. If we take L_i as the distance of the movable lamp from its photoelectric cell when the beam from the fixed lamp is passing through the image into the other cell and L_c as the movable lamp distance, say for a clear space on the film, then the density is given as $\rho = \text{Log} L_i^2/L_c^2$.

TABLE 1.

Strip #	Spot #	Rim density	Center density	% Reduction	lbs./sq. in.
9	1	.2620	.2593	1.0	0
9	2	.2720	.2360	13.2	448
9	3	.2755	.2430	11.8	672
9	4	.2922	.2408	17.6	1567
10	1	.2768	.2195	20.7	2463
10	2	.3004	.2340	22.1	3358
10	3	.2725	.1865	31.5	4253
10	4	.3153	.2090	33.7	6045
11	1	.2760	.1853	32.8	6895
11	2	.2864	.1710	40.3	8600
11	3	.3286	.1915	41.6	10830

[17] Phys. Rev. *6*, 66; 1915.

DATA AND RESULTS

The data given in Table 1 are for glossy bromide paper, P.M.C.#1. The densities of the spots one to four in the strips nine to eleven of Fig. 2 were measured by passing the light through the paper and image as in the case of plates. The densities given in the table are average values of six to eight determinations.

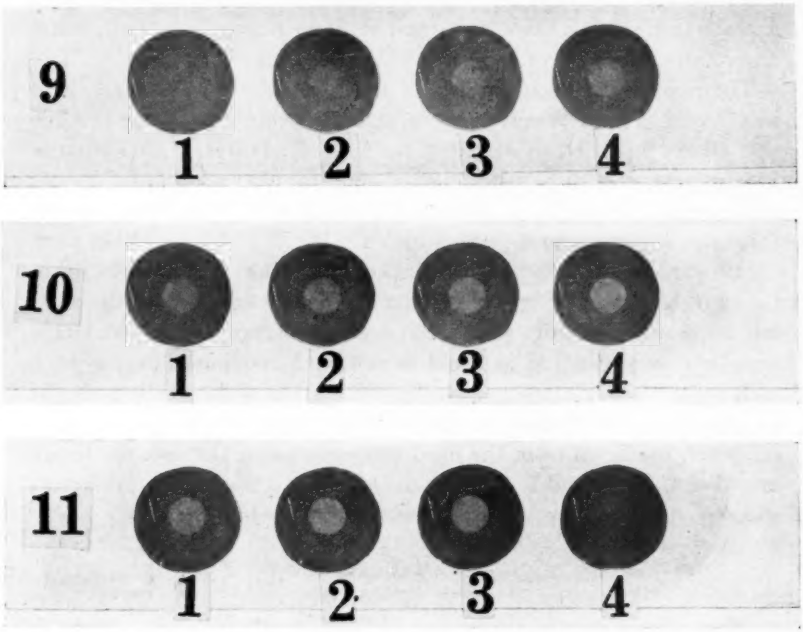

FIG. 2. *The effect of pressure (central spots) on fast bromide paper. The data from these strips are given in Table 1.*

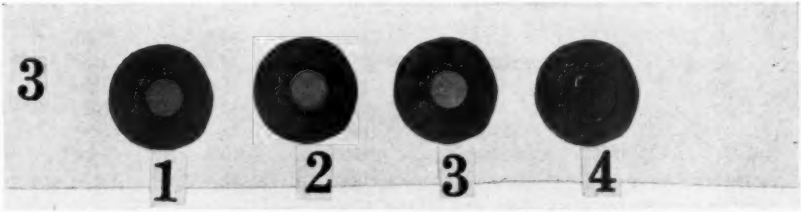

FIG. 3. *A strip of Defender bromide paper which was supported on poor glass during the exposures. The strains in the glass are remarkable.*

The strains in the glass cause considerable fluctuations in the illumination of the spot. Fig. 3 illustrates these strains very markedly. Both the photographic paper and the underlying plate glass used in Fig. 3 were different from those used in Fig. 2, the latter being Defender fast bromide, glossy. The pressures used in Fig. 3 were the same as those of spot 4, strip 10 and spots 1 and 3, strip 11 of Fig. 2. The same pressure as in the preceding spot was applied for one minute then removed before the exposure was made of spot 4 of strip 11, Fig. 2 and spot 4 of Fig. 3. These are of particular interest since they show that the effect of the pressure was temporary in that there is but slight effect left in the film, when the exposure is made immediately after the removal of the pressure. The percentage reduction in density of the pressure areas

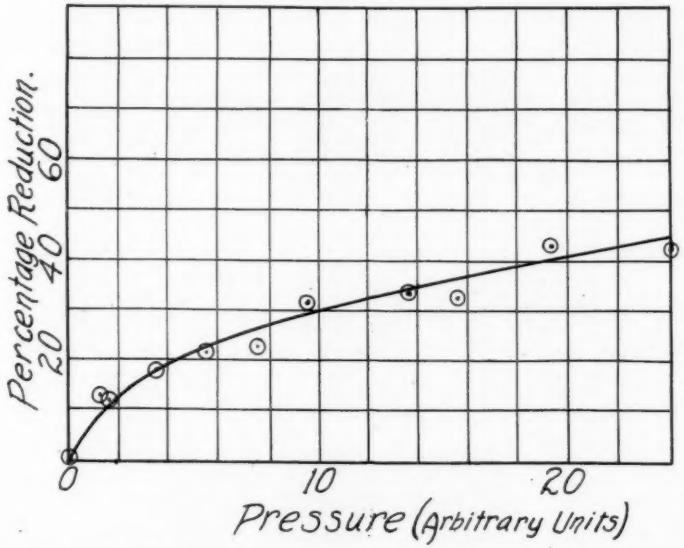

FIG. 4. *A curve showing the reduction in density at different pressures on bromide paper.*

with respect to the areas of no pressure is shown in Fig. 4 as a graph of percentage reduction versus pressure. Since the points are rather scattered, it does not seem worth while to give an empirical equation for the graph. This will come later as the work progresses.

In Fig. 5 are shown some prints made from a positive of some Hammer transparency plates, the pressure varying from 0 to 11000 lbs/sq. in. It will be noticed that the pressure areas are grainy. This is probably

due to unequal grain sizes in the emulsion preventing a uniform distribution of pressure which is fairly well cushioned in the case of the papers used. This graininess is even more pronounced in Hammer Extra fast plates. It is so bad in both plates that it is impossible to draw conclusions from density measurements with our present photometer arrangement. By making the pressure area larger so that a larger area can be measured at one time, it is hoped to overcome this difficulty.

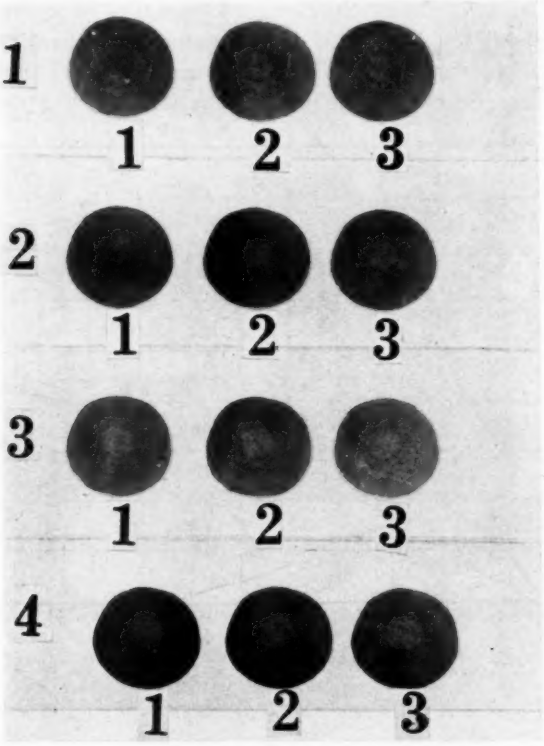

FIG. 5. *A print from a positive made from Hammer transparency plates.*

It is worthy of note that the zero pressure area in the upper left hand corner of Fig. 5 is denser than the rim. This can be ascribed to reflection from the flat polished area of the ball.

The effect of various pads between the steel ball and films of plates has been tested. These give some promise but the results so far are not

conclusive. If anything, the pads add to the effectiveness of the pressure. The plates were exposed from the back, that is, the light passed through the glass of the plate before it reached the emulsion. It was therefore expected that the image would begin developing next to the glass since the time of wetting the film with the developer is very short. Such, however, was not the case. It started on top and developed downward as if it were exposed from the front. Perhaps the pressure in the gelatine has much to do with the speed, the grains of silver bromide in the surface being under less pressure than the deeper lying grains. This is in agreement with the fact that slow plates have thick films.

DISCUSSION

As pointed out in the introduction, it seems quite difficult to account for this pressure effect in the formation of the latent image on the basis of our modern assumption as to matter and radiation. Surely the slight compression of the film and crystals of silver bromide cannot offer sufficient hindrance to the passage of electrons or to photoconduction currents to account for the effects observed. Practically all metals decrease in resistance under pressures far exceeding those used in this experiment.[18] When we look to reflection for an explanation, we are worse off since the closer the film is pressed to the glass, the less reflection we should expect. There is one thing, however, that may account in part at least for the effect, that is multiple reflection in the surface of the film. The films on the plates were velvety in appearance and it was noted that development always started on the air film surface even though the light entered the film from the glass surface. Whether this multiple reflection from grain to grain in the surface is the cause or not will be gone into in the very near future. There is one experimental fact that is against this as an explanation. Various pads were used next to the films of the plates with no apparent diminution in the effect. Even a rather thick, comparatively soft, cardboard pad was used. Had the effect been due to the leveling of the film surface by the polished steel, then we should have got a diminution in the effect when the cardboard was next to the film, since the individual grains and points in the surface would not be crushed and flattened. No diminution in the pressure effect was noticeable with the eye.

The writer wishes to thank Brother A. Zeller for his hearty and efficient cooperation in the construction of the apparatus.

[18] International Critical Tables Vol. VI, p. 135.

MINUTES OF THE EXECUTIVE COUNCIL O. S. A.

Annual Meeting at Charlottesville, Va., Oct. 29–31, 1930.

Besides the transactions of routine business, the following items of general interest to members of the Society were taken up.

1. February Meeting. It was decided to hold a meeting of the Society in New York, February 26, 27 and 28, 1930 one session at the Museums of the Peaceful Arts and one session a joint session with the American Physical Society.

2. Annual Meeting. It was decided to hold the sixteenth annual meeting in Rochester in October, 1931.

3. Date of beginning of membership. The Council voted:

Elections to membership shall be made effective on Jan. 1, either of the year in which the application is made or on Jan. 1 of the succeeding year at the option of the applicant.

4. Publication of Papers in the Journal. The Council instructed the Secretary to place on all announcements of meetings and all abstract blanks the statement:

"By action of the Executive Council the Society reserves the right of original publication of all contributed papers presented at its meetings."

The Council further voted:

The Editors of the Journal are authorized to accept papers for simultaneous publication in the publications of the Society and in institutional Journals when in their judgment the interests of optics are served thereby.

5. A new design for the cover of the Journal of the Optical Society of America was authorized.

6. Colorimetry Committee. The following resolution was adopted. Whereas:

It was reported to the Council of the Optical Society at its February 20, 1930 Meeting that the supply of the report of the Colorimetry Committee 1920–21 published in 1922 was exhausted, but that the demand for it continued, therefore be it

Resolved:

That a committee be appointed to consider the advisability of preparing a revision of the report so as to include later developments, and to further in other ways the progress of colorimetry.

The Council then voted:

A new Colorimetry Committee shall be organized with I. G. Priest as Chairman and such other members as he and the President may choose.

7. "Color Conference." The following resolution was adopted.

Resolved:

It is the sense of the Executive Council of the Optical Society of America that the need for better organization of those interested in the description and specification of color which found expression at the "Color Conference" held in Washington, May 14, 1930 (at which conference the Optical Society was officially represented) can best be met by the formation of a joint Council consisting of officially designated representatives of the several national societies and associations interested in the description and specification of color.

8. Closer cooperation of Societies. The following resolution was adopted.

Resolved:

That the Council approves of the effort to establish closer relations between the various Societies interested in Physics and approves a continuing committee of presidents of the several societies concerned to consider ways and means for furthering this purpose.

9. Directory of Members. The Secretary reported that he had been unable to prepare a directory during 1930. The Council decided to publish a directory early in 1931.

10. Transfers from Associate to Regular Membership. The name of each associate member with the recommendations from the Committee on Transfer were taken up in order, and the following members were transferred to Regular Membership:

J. B. Austin (798 R)
L. E. Barbrow (736 R)
Frederick S. Brackett (844 R)
Arthur Bramley (817 R)
Frederick Lyons Brown (597 R)
Edna Carter (755 R)
Clement D. Child (820 R)
William Edward Curtis (833 R)
Elmer Dershem (804 R)
E. O. Dieterich (794 R)
Paul Harrison Dike (862 R)
Thomas E. Doubt (766 R)
Frank E. Duckwall (636 R)
John C. Duncan (578 R)
H. E. Farnsworth (840 R)
E. E. Free (762 R)
Frederick L. Gates (789 R)
William C. Geer (767 R)
Frank Arthur Geldard (857 R)
I. H. Godlove (858 R)
Vincent C. Hall (453 R)
David A. Keys (801 R)
Rudolph Kingslake (756 R)
Vladimir Paul Lubovich (761 R)
W. C. McQuarrie (763 R)
W. A. Marrison (479 R)
George Spencer Monk (783 R)
D. W. Morehouse (796 R)
J. Rud Nielsen (831 R)
C. V. Raman (836 R)
William F. Roeser (835 R)
F. F. Rupert (567 R)
Ancel St. John (788 R)
Willard L. Severinghaus (812 R)
James Stokley (861 R)
Clifton M. Tuttle (424 R)
E. P. T. Tyndall (853 R)
William W. Watson (856 R)
David T. Wilber (827 R)
P. I. Wold (822 R)

L. B. TUCKERMAN, *Secretary*

Traite de Polarimetrie. By Georges Bruhat. xvi+447 pages. Published by the Revue d'Optique théorique et instrumentale, 1930.

The author limits his treatment to rotatory polarisation with only such discussion of elliptically polarised light as is necessary for the presentation of circular dichroism. The book is avowedly written for the physicist, the chemist and the worker in the industrial laboratory who is concerned with saccharimetry and related applications. The first half of the book deals in a most excellent manner with the instruments of polarimetry. A very brief treatment of polarised light is followed by detailed descriptions of polarising prisms, special types of analysers and half-shade elements for determining the plane of polarisation, polarimeters, saccharimeters, sources of illumination and methods for determining rotatory dispersion and circular dichroism. The second half of the book discusses the rotatory power of crystals and liquids, rotatory dispersion, saccharimetry, magnetic rotation and magnetic rotatory dispersion. This part of the book, although dealing in part with the theory of the subject, places great emphasis upon the technique, methods and results of experimental work. There are 27 pages of bibliographical references, a complete index of subject matter, an 8 page index of authors to which reference is made in the text and a table of contents. This is an excellent treatise, well fulfilling its purpose and of particular interest to one concerned with the design of apparatus for polarimetric work.

I. C. GARDNER

Photocells and their application. By V. K. Zworykin, E. E., Ph D. and E. D. Wilson, Ph. D. Research Engineers of Westinghouse Research Laboratories. vii, 209 pages. John Wiley and Sons, Inc. New York; Chapman and Hall, Ltd. London. $2.50.

The book contains a historical introductory chapter on the early experiments of Herz (1887) and briefly traces development through to Elster and Geitel's hydrogenated alkali cells of 1912. Then follows a concise chapter on general radiant energy theory through Einstein's photoelectron equation and the experimental verification by Millikan and others, the whole giving a suitable theoretical background for a practical understanding of photocell performance.

Chapter III and IV describe mechanical features of photocell construction and general methods of preparation, including the more recent high-sensitivity cells—Zworykin's cesium-magnesium cell; Koller and Thomson's cesium-oxide-silver cell and others.

The electrical characteristics of the vacuum and gas-filled photocells are next discussed in leading up to the practical applications of such cells in conjunction with suitable thermonic amplifiers. A brief chapter on photoconductive (ie. selenium) and photovoltaic (electrolytic) cells is included.

Chapters VIII to XIII are devoted to various photocell-amplifier circuits and their use in practical devices including typical picture transmission and television apparatus.

A final chapter on future development points out the necessary and probable development of photocells having high red and infrared sensitivity.

In this 209 page book the general reader will find a good introduction to the theory and the practical applications of the modern "electric eye" and the average technical reader will find considerable information of value.

The book contains bibliography and technical journal references.

R. D. WYCKOFF

OPTICIAL SOCIETY OF AMERICA

Election of Secretary

The Tellers appointed to canvas the ballots for the election of Secretary for the term January 1, 1931 to December 31, 1935 have reported that L. B. Tuckerman received 188 votes out of the 196 ballots sent in. He is therefore elected secretary.

[Signed] Loyd A. Jones, President.

Rochester, New York
December 1, 1930.